The Denny Way Sediment Cap 1990-1992 Data

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THE DENNY WAY SEDIMENT CAP

By

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EXECUTIVE SUMMARY

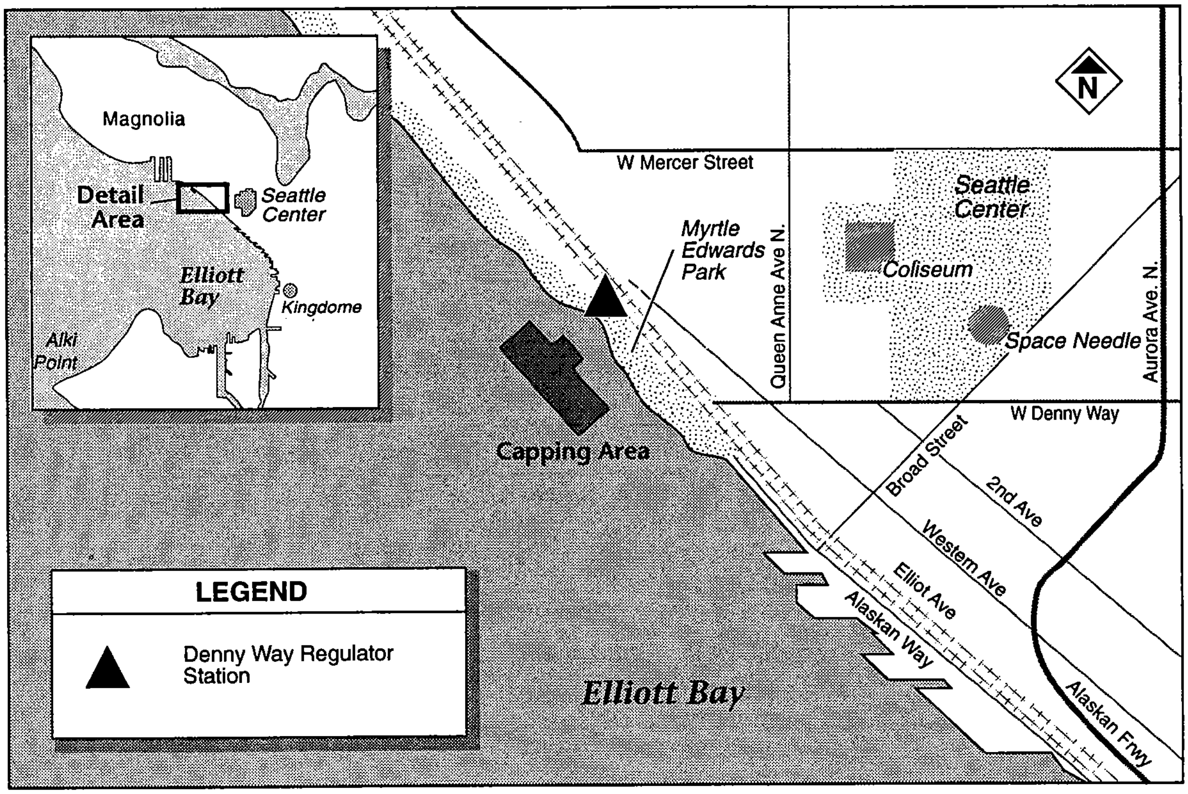
The Denny Way sediment cap is a demonstration project intended to remediate contaminated bottom sediments offshore of downtown Seattle in Elliott Bay. The project involves covering contaminated sediments, located near a historic untreated sewer outfall, with a 3-foot-thick layer of clean sand. The cap is intended to minimize exposure of benthic organisms, fish, and ultimately, humans to the contaminants. It covers 3 acres located offshore of the Denny Way combined sewer overflow (CSO), which is in the north end of Seattle's downtown waterfront (see Map 1). A 5-year monitoring program will determine how stable the cap is, how well it is functioning to isolate the contaminated sediments, whether it continues to meet Washington State Marine Sediment Quality Standards for the cleanup action, and how it is biologically recolonized.

This report has two purposes. First, it is intended as a source of background information and studies related to the Denny Way sediment cap. And second, it contains the results of 3 years of monitoring required by the monitoring plan.

BACKGROUND

Capping is a relatively new method for remediating contaminated bottom sediments; it was developed within the past 10 years. Initial projects involved dredging and relocating contaminated sediment and then isolating them from the marine environment with a clean cover layer. This is known as confined aquatic disposal or CAD. One of the disadvantages of CAD is that the initial dredging of the contaminated sediments can redistribute the contamination into the water column and surrounding area. Covering contaminated sediments in place called, here, sediment capping, eliminates the expense of dredging twice and the possibility of contaminating the area surrounding the project.

There were several reasons sediment capping was chosen to remediate the Denny Way site. First, the cap would improve sediment quality immediately in contrast to the 20 to 60 years it would take for new sediment to accumulate through natural processes. Second, the cap would cover historic contaminated areas, making it easier to identify current pollutant inputs by monitoring the cap surface. Third, the cost of remediating contaminated bottom sediments by capping can be 1 to 20 percent of the cost of dredging the contaminated material and disposing of it in an acceptable facility, assuming an acceptable facility could be



Map 1. Location of the Denny Way Capping Site

found. Fourth, conventional dredging and disposal equipment can be used. Finally, this project will provide information and experience to expand our understanding of capping as a tool for improving environmental conditions in Puget Sound.

Environmental monitoring for the project is specified in the Monitoring Plan for Denny Way (Appendix A); the plan includes short-term activities needed for cap placement as well as long-term activities documenting how well the cap functions. The long-term monitoring strategy called for intensive monitoring the first few years after capping, followed by less frequent monitoring as appropriate. A 5-year monitoring plan was adopted and is currently underway. Monitoring will continue for 2 more years, at which time future monitoring requirements will be determined after review and discussion by the permitting agencies.

PRE-CAP STUDIES

Several studies of the Denny Way CSO marine sediments and a study of the pre-dredge Duwamish River sediments contributed needed information to the Denny Way capping project. This section summarizes five studies: *Fate and Effects of Particulates Discharged by Combined Sewers and Storm Drains* (Tomlinson et al. 1980), *Toxicant Pretreatment Planning Study* (Comiskey et al. 1984 and Romberg et al. 1984), *Toxicant Reduction in the Denny Way Combined Sewer System* (Romberg et al. 1987), Waterfront sediment studies in 1988 and 1989, and a study of the pre-dredge Duwamish River Sediments in 1989.

Fate and Effects of Particulates Discharged by Combined Sewers and Storm Drains

In 1980, Tomlinson et al. completed the study *Fate and Effects of Particulates Discharged by Combined Sewers and Storm Drains* for the Environmental Protection Agency. The study investigated the fate and ecological effects of particulates in stormwater runoff and combined sewer discharges entering Lake Washington from several outfalls and in the discharges entering Puget Sound from the Denny Way CSO. The following summary is focused on the information gathered at the Denny Way CSO.

The area 200 to 300 meters along the shore in both directions from the outfall was measurably affected by settling particulates. Surface sediments near the outfall showed evidence of heavy inputs of CSO particulates. Studies of the local aquatic biota showed that the nearshore area within 150 meters of the CSO could be referred to as polluted. The relative effects were evident at the 9-meter depth contour, but diminished offshore at the 13-meter depth level. There was some evidence that the shallow subtidal infauna underwent a small degree of recovery during periods of few overflows.

Toxicant Pretreatment Planning Study

In 1984 Metro completed the *Toxicant Pretreatment Planning Study* (TPPS), which was a multiyear effort designed to provide basic information and answers concerning local toxicant issues.

One of the goals of the TPPS was to determine the status of toxic chemicals in Puget Sound and Lake Washington as a basis for making facility planning decisions regarding toxicant removal. In the Denny Way area, 10 stations were sampled for both sediment chemistry and benthic infauna.

While there were no established sediment criteria for evaluating chemical concentrations, the levels found in Puget Sound were compared with other areas. Concentrations in the main basin tended to fare well in such comparisons, while high values in Elliott Bay often exceeded many of the reported levels from other urban areas, and were surprisingly close to concentrations found in such places as the heavily polluted Houston Ship Canal. These comparisons, and the fact that fish disease and altered benthic communities occur in Elliott Bay and the lower Duwamish River, where there are important biological resources, led to the conclusion that sediment chemical concentrations in these areas are a problem.

Based on biological community structure analyses, the Denny Way CSO was unquestionably having a detrimental effect on the organisms in the immediate vicinity of the outfall, out to at least 30- to 40-meter depths. It is difficult to attribute pollutant effects to any particular source in an area with numerous inputs, but those around the Denny Way CSO were fairly distinct. The effects appeared to be local in nature, and the CSO did not appear to be contributing substantially to the toxicant burdens in the rest of Elliott Bay.

Toxicant Reduction in the Denny Way Combined Sewer System

In May 1986, Metro began a trial program aimed at identifying and reducing toxicants going into the sewer system that is tributary to the Denny Way CSO. The program was an interim approach to improving environmental conditions at the Denny Way CSO site before overflow volumes are reduced by capital construction projects that will be completed in 1999.

Part of the program focused on reducing toxicants discharged by commercial businesses. A questionnaire survey and site visits were used to obtain information about business use and disposal of toxic chemicals. Samples were taken from the sewer system to identify chemicals and their sources. By means of return visits, written instructions, and permitting requirements, many of these inputs were reduced.

Offshore of the Denny Way CSO, 29 subtidal sediment samples were collected in an effort to define spatial distribution of contaminated sediments. This study showed that the two stations nearest the outfall had the highest chemical concentrations. Chemical concentrations decreased with distance offshore (increasing depth). Concentrations also decreased moving alongshore away from the outfall in both directions, but not as rapidly as moving offshore.

The study concluded that toxicant reduction projects can reduce chemical inputs into Elliott Bay and that a sediment cap could improve environmental conditions offshore of the Denny Way CSO.

Waterfront Sediment Studies: 1988 and 1989

Metro conducted sediment studies in 1988 and 1989 along the Seattle waterfront in an effort to better define areas of contamination identified by previous studies. During the waterfront studies, three intertidal sediment samples were taken just offshore of the Denny Way CSO to further develop the Denny Way capping plan. The results showed elevated levels of polychlorinated biphenyls and high and low molecular weight polycyclic aromatic hydrocarbons. The intertidal samples provided background data for the capping project, confirmed the sediment quality findings of previous studies, and showed shoreline conditions relative to offshore conditions.

Duwamish River Sediment Study

The sediment used for the Denny Way cap came from the upper navigable waterway of the Duwamish River. Before the sediment could be dredged, it was sampled and analyzed according to Puget Sound Dredged Disposal Analysis (PSDDA) disposal guidelines for dredged sediments. All testing concerning the suitability of the dredged material for the Denny Way capping project was based on the PSDDA standards for unconfined, open-water disposal of dredged material. The Army Corps of Engineers conducted the sampling, taking four sediment core samples and making four composite samples from the area where the capping sediments were to be dredged. Two composite samples were made to characterize the sediments from the surface to a depth of 4 feet, and two composites were made to characterize the sediments from the 4-foot depth to the 12-foot depth.

The results showed that the Duwamish River sands met the PSDDA minimum screening levels for organic and metal contaminants. There were as many as 15 semivolatile organic compounds detected in the composites, but all were at levels much lower than the PSDDA minimum screening levels. No pesticides or PCBs were detected in any of the samples. Nine metals were tested for and all were found to be well below the PSDDA minimum screening levels.

CAP PLACEMENT

This section documents the first two objectives in the monitoring plan for the Denny Way project. The first objective is to ensure that water quality standards for dissolved oxygen are maintained during cap placement. The second objective is to report the sediment-cap placement, thickness, and settlement. In addition, the sediment-profile camera survey is discussed in this section as it relates to the placement of the cap.

Water Column Dissolved Oxygen Level

The increase in turbidity of the local water column during cap placement was a concern to the permitting agencies. Therefore, the agencies required that water column monitoring be included in the monitoring plan as a permit condition. Capping was to stop if the dissolved oxygen levels dropped below minimum standards or if there were any fish observed to be in distress within the capping area. However, if monitoring during the initial barge dumps showed no problem with oxygen levels, then monitoring could be discontinued.

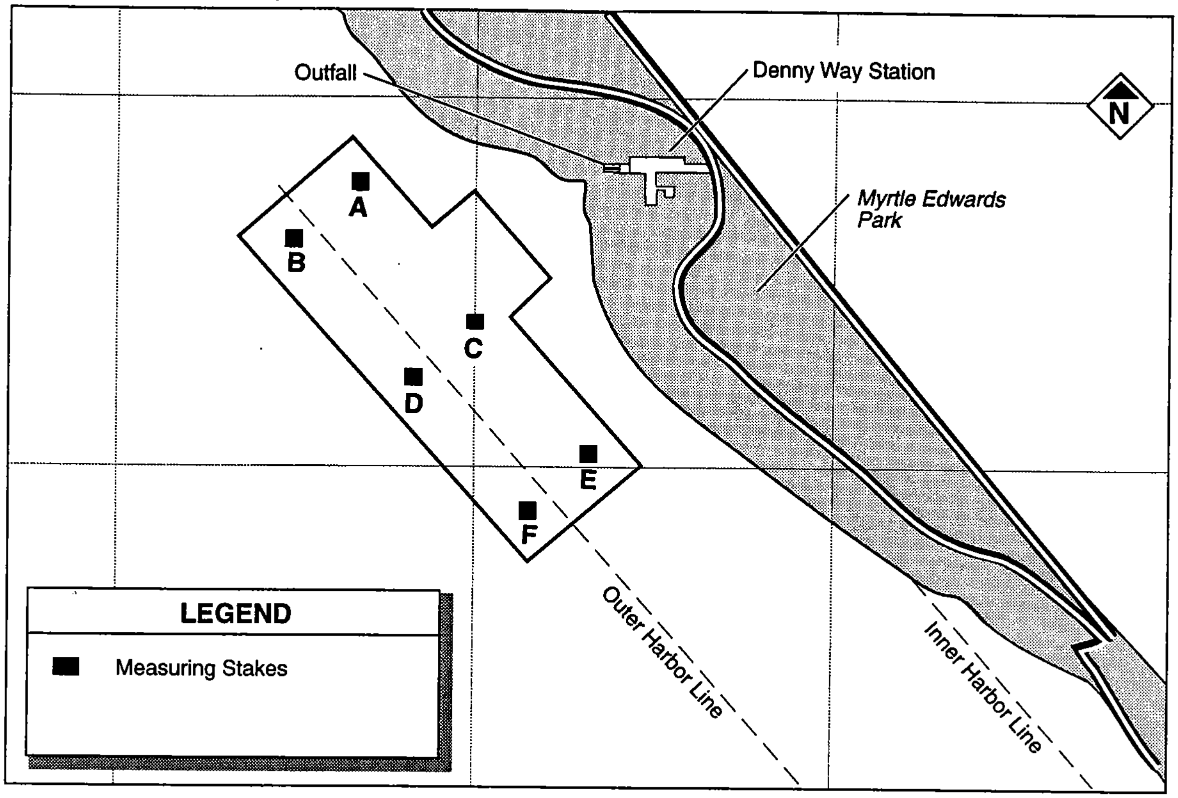
Water column samples were collected at two sites during cap placement. The first was within the capping zone and the other was a reference sample outside of the capping zone. The results showed that the dissolved oxygen levels never dropped below 7.8 mg/liter, which was well above the *Water Quality Standards for Surface Waters of the State of Washington* criteria of 5 mg/liter for Elliott Bay.

Cap Placement

Contractors placed the sediment cap at the Denny Way site by using a split-hulled bottom-dump barge. Thirteen barge loads were spread at the capping site. Cost and available equipment were major factors in the decision of how to place the sediment cap. The bottom-dump barge sand spreader system applies a large amount of sand over a large area at one time, cutting time spent in the application process and therefore cost. Another advantage of the system is that it eliminates the need to transfer the sediment from the transporting barge to the bay bottom with a crane or other transfer method.

Cap Thickness

Cap thickness was measured directly using measuring stakes that were installed before the cap was placed. Thicknesses were estimated during capping using a simple calculation that considered the amount of sand in a barge load and the size of the area over which it was spread. The objective was to create a cap 3 feet thick over the entire project area. This was achieved on about half the site; on a quarter of the site the cap is slightly less than 3 feet, and on the other quarter it is, in places, only 1.5-feet thick (see Map 2).



Map 2. Barge Tracks and Measuring Stakes

There were a few apparent causes for the discrepancies in estimated thickness and actual thickness. First, to estimate thicknesses, simple calculations were used that assumed all sand would pile up exactly within the designated barge track. Second, there appeared to be alongshore currents that caused a considerable amount of sediment to drift offsite. Third, long barge tracks made it difficult to judge the proper deposition rate and occasionally there would be sand left in the barge at the end of a dump run. It was difficult for the tug operator to spread this remaining sand back over the entire barge track. And finally, the tug that was attached to the broadside of the barge to provide propulsion was frequently put in reverse and used to drag the barge over the target area. The propeller wash then went under the barge and likely caused a greater dispersion of sand. In the subsequent capping project at Pier 53–55, the Army Corps of Engineers shortened the barge runs by half, avoided using the side tug in reverse, and factored in currents, all of which resulted in greater control and less sand loss.

Sediment-Profile Camera Survey

The primary focus of the sediment-profile camera survey was to document how far outside of the project boundary the capping sands settled. The survey showed capping sands up to 210 feet beyond the cap boundary in the offshore (downslope) portion of the survey area. Cap material was not evident inshore of the project boundary. In one area images showed the capping sands to be only 10 centimeters thick on the inshore edge of the project boundary, suggesting that the inshore edge of the cap is thin. Inshore of the cap, pictures showed rock and gravel with no sand on top. This is likely because care was taken during capping not to bury the kelp bed that is inshore of the capping area.

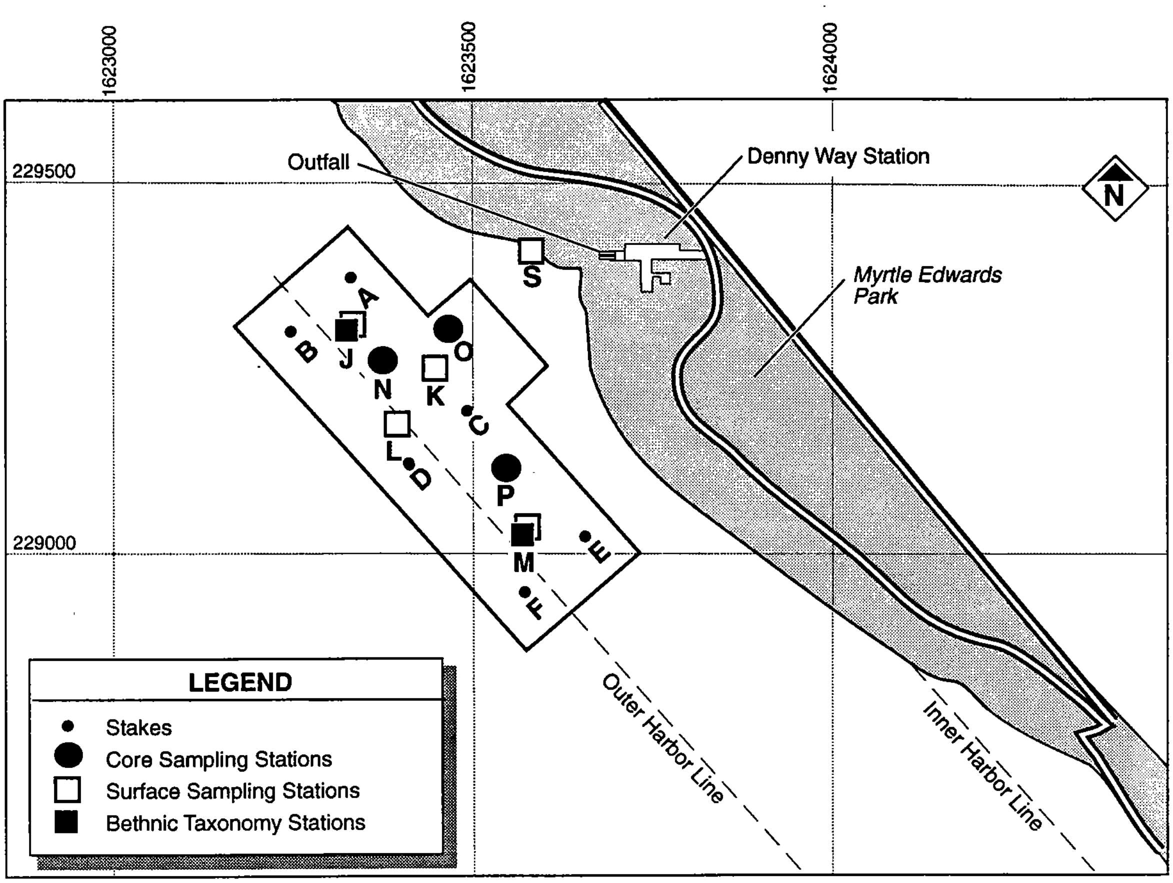
CORE SAMPLE ANALYSIS

This section describes the vertical-core sediment sampling of the cap and compares the chemistry of the cap to the under-cap sediments, the Duwamish River sediments, and the state sediment standards for 3 years of study.

Three coring stations were established to provide spatial coverage across the sediment cap (see Map 3). Each core extended completely through the clean capping sediments and into the underlying contaminated sediment by about 1 foot. The cores were subsequently divided into 6-inch sections and analyzed for organic and metal contaminants.

Three years of core samples showed that the concentrations of metals and organics were low and nearly uniform throughout the cap. There were no spatial differences of chemical concentration within the cap. A consistent and sharp contrast between the capping sediments and the contaminated underlying sediments showed that there are no chemicals migrating up into the cap from below.

Sampling conducted 2 months after cap placement provided baseline conditions. In the samples, 21 organic compounds were found below the cap but only six were found anywhere within the cap, except for a section in one core that contained contaminated clay presumably dredged from the Duwamish River. Only trace levels of organic compounds were measured in the cap. Concentrations of metals were much lower in the cap than in the underlying sediments. All within-cap values were well below the state sediment quality standards (SQS). Some standards were exceeded below the cap at Station O, which was closest to the outfall, and at Station N.



Map 3. Post-Cap Sampling Stations

The low concentrations of organic compounds and metals in the cap material were very uniform across the cap, in marked contrast to the pattern found below the cap. The station nearest the outfall had the highest below-cap concentrations, while the two stations farther away from the outfall were noticeably less contaminated.

The concentrations of most organic compounds below the cap were much lower in 1991 and 1992 than 1990. The large drop in PAH concentrations in all cores was probably due to a sampling artifact. Cores had to be jackhammered in 1991 and 1992 instead of rotohammered because the core tube was not able to penetrate through the sand cap. Less contaminated underlying sediments may have been collected because of this change in sampling method. Still, there was a distinct interface between the cap material and the contaminated below-cap sediments for all years.

The organic-carbon content was higher in 1992 for many within-cap sections, causing the TOC-normalized values and detection limits to be lower in general. All compounds or metals within the cap were well below the SQS. Below the cap, mercury, silver, bis(2-ethylhexyl)phthalate, and total PCBs exceeded the state cleanup screening levels (CSL) on occasion.

SURFACE SAMPLE ANALYSIS

This section describes surface sediment sampling of the cap. Findings for the initial baseline study and two annual studies are summarized and compared to the Duwamish River sediments and to the state sediment standards.

Four surface sampling stations were established to provide spatial coverage across the cap. A fifth station was located in the intertidal zone inshore of the cap near the outfall in an effort to link changes on the cap to the outfall.

Chemical concentrations found on the cap in the 1990 baseline study showed that the cap surface was very much like the pre-dredge Duwamish River sediments and the within-cap core samples. Five PAHs and 11 metals were found in all four cap surface samples. Three additional PAHs and two additional organic compounds were found in at least two other cap samples. There was little if any spatial variation; the southernmost site (M) had the fewest detected chemicals and the lowest concentrations while the other three were virtually identical. All concentrations were well below the SQS.

Baseline study of the intertidal Station S, which is inshore of the cap and near the Denny Way CSO, showed that concentrations were similar to those of the capped sediments. Of the 20 semivolatile organic compounds found below the cap, 17 were detected at Station S. Most metals concentrations at S were within the same range or lower, while concentrations of three metals were higher at S than in the below-cap values.

The second study in 1991 showed increases in the number of compounds detected at all of the on-cap stations and increases in the concentrations of previously detected compounds. At least nine PAHs were detected compared to five PAHs in 1990. The average concentration of previously detected PAHs increased two- to eight-fold. Average metals concentrations increased at slower rates than the PAHs. Silver was detected at the three northern sites. Trace amounts of one PCB appeared at each of the four on-cap sites. Pesticides and volatile organics remained absent. The intertidal uncapped site, Station S, was largely unchanged from 1990.

The baseline study showed that the cap surface was reasonably homogeneous, while in 1991 distinct spatial differences developed in the distribution of PAHs. The on-cap station closest to the outfall and shore (K) showed the largest increases. Stations seaward (L) and north (J) of K were subject to lower but still considerable increases. The station to the south (M) was the least affected.

Spatial differences in the distribution of metals were not as apparent. All four stations showed increases. In general, the three northern stations had similar compositions, but with concentrations only slightly higher than those found at the southernmost station.

In 1992, concentrations and the number of parameters detected continued to rise. At least 12 PAHs were detected at each station, up from nine the year before. Three more metals, cadmium, antimony, and thallium, were detected for the first time, at all four stations. At Station M, PAH concentrations rose more than they had between 1990 and 1991. Rates of PAH increases at the other three stations were lower than the previous year. Lead, mercury, and silver were the only metals to increase noticeably.

The spatial differentiation between stations was not as distinct as 1991. Station K, which is closest to shore and nearest to the outfall, continued to have the highest concentrations and the most compounds detected, but spatial differences between the other three stations became less pronounced. The most substantial increases occurred at Station M, changing its composition to be more comparable to Stations J and L. Station L showed the least amount of change. Much lower chemical concentrations at the intertidal station brought many of its values to within the same range as those found on the cap.

A storm discharge that scoured nearshore and intertidal contaminated sediments in 1992 did not cause recontamination of the cap. Concentrations were unchanged or lower at one of the two stations where post-storm samples were collected. The other station did not appear to be significantly affected.

Of the 10 HPAHs detected on the cap, the highest concentrations were mostly less than 10 percent of the SQS, but two were less than 15 percent. Total HPAHs were also less than 10 percent of the SQS. All LPAHs that were detected on the cap were less than 10 percent of the SQS. The data shows that LPAHs are increasing slower than HPAHs. Total PCBs increased between the studies and were less than 35 percent of the SQS.

Most metals were less than 10 percent of the SQS, while zinc was less than 15 percent and mercury for all samples except one was less than 35 percent of the SQS. The one exception was Station M, the farthest away from the Denny Way CSO, which had a suspiciously high value that exceeded the CSL. Additional samples are needed to confirm this value.

One phthalate showed variable concentrations over the three studies with the highest concentration in 1991. In 1992, one phthalate was less than 45 percent of the SQS while another was about 20 percent.

Evaluation and comparison of detection limits to the sediment standards was difficult in the first two studies because of the low organic carbon content of the samples. When the low TOC values were divided into the detection limit concentrations for some compounds, the resulting TOC-normalized detection limits exceeded the sediment standards. In the 1992 study, the organic carbon content had increased and reduced the number of detection limit exceedances of the sediment standards.

Video-camera surveys conducted in 1990, 1991, and 1992 (see Section 6) showed a layer of fine silt mixed with organic debris and plant growth on the cap surface that increased in thickness each year. The same layer was also noted in the sediment-profile camera survey (see Appendix D), but was absent in some areas of the cap, possibly because of disturbances from boat anchors, anchor lines, and the diver dragging his air hoses across the bottom.

The contamination found on the cap surface one year after capping and later is presumably present in the fine material. The two potential sources of the contaminated fine sediments were solids discharged from the outfall or contaminated nearshore sediments redistributed onto the cap by storm waves in shallow water. Stormwater samples have been analyzed but not interpreted yet, and additional sediment sampling is being planned to investigate the nearshore area. Additional intertidal and nearshore sites will be considered during the 1994 sediment sampling efforts at the cap. However, because this layer of fine organic debris was present right after capping, it appears to initially to have come from the capping material as a result of less dense material settling more slowly than the sand and producing a fine layer on the cap surface.

BENTHIC RECOLONIZATION

This section describes the 3 years of benthic taxonomy studies conducted after the Denny Way cap was placed. The first samples were collected in August 1990, 5 months after cap placement, and subsequent samples were collected 17 months and 29 months after cap placement. Comparisons made from year to year show how the cap is being recolonized. A sediment-profile camera survey was conducted in 1991 to document the extent of sand placement and biological conditions.

Two of the cap surface sampling stations were used for benthic taxonomy studies. Five replicate samples were taken from each benthic taxonomy station. The samples were analyzed for the number of individual organisms, the number of species, and biomass weight in five replicate samples.

Three-year trends that were apparent from the benthic data showed the average number of individuals per sample doubled from 1990 to 1992 and the number of species and biomass steadily increased over the three annual studies. Polychaetes were usually the most abundant, had the greatest number of species, and had the highest biomass weight. Over the three sampling periods, however, the relative dominance of polychaetes was steadily being challenged by the rise in number of individuals, number of species, and biomass weight of crustaceans and mollusks.

Polychaetes increased in abundance from an average of 232 individuals the first year to an average of 380 individuals the second year and then decreased slightly to 360 individuals the third year. The number of polychaete species increased from 76 species in 1990 to 83 in 1991 and 91 in 1992, making them the most diverse taxonomic group on the cap. Polychaetes were also the cap's most dominant group in terms of biomass, accounting for 53 percent of the cap's biomass weight.

Crustaceans became the most abundant taxonomic group on the cap in 1992. They steadily increased over the 3 years from an average of 23 individuals the first year to an average of 124 individuals the second year and 360 the third year. At the same time, the number of crustacean species increased from 24 in 1990 to 35 in 1991, then decreased to 27 in 1992.

Large numbers of juvenile *Macoma* caused mollusks to be the most abundant in 1990, with an average of 232 individuals. In the following 2 years, *Macoma* was not as abundant, and mollusks dropped to an average of 68 individuals in 1991, then increased to 152 individuals in 1992. Mollusk species remained constant beginning with 33 in 1990 then increasing to 34 in 1991 and 37 in 1992.

The two taxonomy stations, M to the south and J to the north, were compared using abundance, number of species, and biomass to determine relative productivity of different areas of the cap. Although the differences were commonly small, Station M was more productive than Station J in all categories.

Further monitoring and a control station in a similar environment without a CSO influence would be needed to determine if the CSO is now having an effect on the diversity of the benthic community and whether the benthos can be considered affected by the outfall volumes.

Diver-held video camera surveys were conducted in May of 1990, soon after the sediment cap was installed, in 1991, 1 year later, and in 1992, 2 years later. Compared to other methods of collecting information about the cap and the cap biology, the video surveys were the least expensive and provided spatial coverage over the largest area. The three videos showed the gradual recolonization of the cap by plant and animal life. The earliest video showed a mostly flat cap devoid of any benthic life except for a few crabs and flounder. The video also showed a thin, approximately quarter-inch-thick, layer of silt, detritus, small wood twigs, and plant life. Also shown on the cap surface were some basketball-size clumps of compacted leaves and clay, which were presumably dredged along with the sediment from the Duwamish River. Successive videos showed increasingly more plant life, signs of benthic invertebrates, scavengers, and predators. The thin layer of silt, detritus, and plant life also increased in thickness during successive years to up to one inch thick in one place, as reported by the diver in 1992. All three videos showed no evidence of cap erosion. However, the video clearly showed that the cap surface was disturbed by the diver's air hoses, the camera cord, and the boat anchor and lines, which wiped away the thin layer of fine material leaving a clean surface exposed.

A second type of survey was conducted using a sediment-profile camera, which penetrates the sediment up to 8 inches and obtains a photo of the vertical depth strata. The sediment-profile survey provides additional information on the nature of the benthic communities recolonizing the cap. Images from the survey conducted 19 months after capping showed that the cap is slowly being recolonized, starting around the edges and moving inward. Organisms making up the benthic communities are dominated by species that are usually first to recolonize a recently disturbed area. As the recolonization process continues it is expected that the makeup of the benthic community will become more like those found in stable environments.

CONCLUSION

The Denny Way sediment cap has been successful in achieving its primary purpose of isolating contaminated bottom sediments, thereby providing a clean substrate for marine life. The overall project proceeded as expected with minor variations from the original plan. The planned cap thickness of approximately 3 feet was obtained over about three-quarters of the capping site. Calculations showed that 5,000 cubic yards or 25 percent more capping material was used than the volume calculated as necessary for covering the capping area to a 3-foot depth.

Monitoring was conducted 1 and 2 years after cap placement. Cap thickness measurements show that no erosion occurred on the cap surface. Core samples show that no chemicals migrated up into the cap from below. Surface grab samples show that, as expected, chemical levels increased on the cap surface; however, the values are mostly less than 10 percent of the SQS. Surface grab samples show that benthic organism rapidly recolonized the cap surface after 5 month and the number of individuals doubled after 2 years.

Cooperation between Metro and the Corps substantially reduced the cost of the Denny Way project. The Corps provided the clean dredged material for the cleanup from an existing project using conventional dredging and disposal equipment. The project cooperation and the method of capping contaminated bottom sediments with a clean layer of sand have potential for economical remediation of contaminated sediments.

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ILLUSTRATIONS (continued)

TABLES

TABLES (continued)

SECTION 1

INTRODUCTION

In March 1990, contractors for the US Army Corps of Engineers (the Corps) slowly placed 20,000 cubic yards of clean sand offshore of the Denny Way combined sewer overflow (CSO), capping 3 acres of chemically contaminated bottom sediments. The sediments were capped to minimize exposure to and consumption of contaminants by benthic organisms, fish, and, ultimately, humans. This project (known as the Denny Way sediment cap) was the result of several years of research by many agencies and a cooperative effort between the Corps and the Municipality of Metropolitan Seattle (Metro).

The CSO is located at the foot of Denny Way in Myrtle Edwards Park, at the north end of Seattle's downtown waterfront. Combined stormwater and wastewater may flow out of the CSO and into Elliott Bay during major rainstorms. The cap is situated in a northwest to southeast rectangular area approximately 150 feet offshore (see Map 1-1).

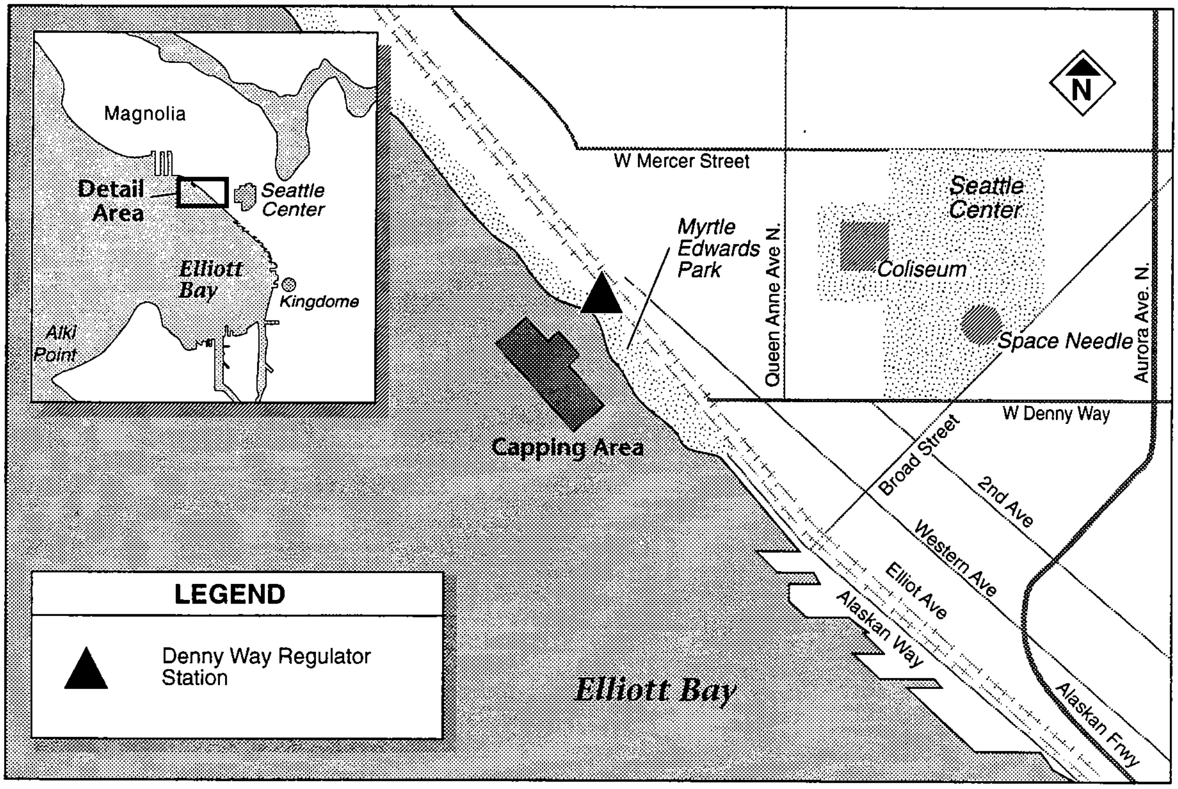
Metro began planning this project after a 1987 Metro study, *Toxicant Reduction in the Denny Way Combined Sewer System*, recommended capping these sediments. The Denny Way project is now part of Metro's Toxic Sediment Remediation Program, which was developed to administer that project and any future sediment remediation projects. The program was designed to help coordinate and plan multiagency efforts to clean up contaminated sediments in Elliott Bay and the lower Duwamish Estuary prior to the establishment of state sediment standards.

This report has two purposes. First, it is intended as a source of background information and studies related to the Denny Way sediment capping project. Second, it satisfies requirements set forth in the approved *Monitoring Plan for the Denny Way Sediment Cap* (Appendix A). The monitoring plan lists six objectives and provides an outline for the periodic monitoring report. The monitoring objectives are the following:

- Ensure that water quality standards for dissolved oxygen are maintained during cap placement.

- Guide and document the sediment cap placement and thickness.

Background



Map 1-1. Location of the Denny Way Capping Site

- Document how well the cap functions to isolate contaminated sediments from migrating upwards into the cap.
- Determine whether chemicals accumulate in the surface of the cap in a way that indicates a need for additional toxicant source control upstream in the Denny Way collection system.
- Determine the amount and type of benthic recolonization that occurs in the capping area.
- Review and evaluate the monitoring data to determine (1) whether the cap is functioning as expected and (2) whether further actions are warranted in the capped area.

BACKGROUND

Considerable research and planning went into the decision to cap some of the contaminated sediments offshore of the Denny Way CSO. This subsection reviews previous studies, site selection, the history of the CSO, and the choice of a sediment cap for remediation.

Previous Studies

Several sediment monitoring studies have identified the Seattle waterfront and Harbor Island areas as problem spots because of elevated levels of toxic chemicals in bottom sediments (Armstrong et al. 1978, Malins et al. 1980, Tomlinson et al. 1980, Romberg et al. 1984, Comiskey et al. 1984). A report prepared in 1986 by Tetra Tech, Inc. for the Elliott Bay Action Program, a multiagency program aimed at controlling sources of contamination in Elliott Bay, ranked the nearshore area by the Denny Way CSO as the second most contaminated of approximately 30 identified "toxic hotspots" in Elliott Bay and the Duwamish Waterway. The 1987 Metro study by G.P. Romberg, D. Healy, and K. Lund, *Toxicant Reduction in the Denny Way CSO*, focused on ways to reduce pollutant inputs from industries. It proposed sediment capping as an interim measure to improve environmental conditions. Another study by Tetra Tech, *Analysis of Toxic Problem Areas* (1988), was conducted as part of EPA's Puget Sound Estuary Program. All of these studies influenced Metro to investigate cleanup actions at the Denny Way site.

Site Selection

Under the 1972 federal Clean Water Act, Metro applied to be, and was designated, a regional water quality planning agency. One of its goals under this act is to protect the region's marine water resources from pollution. Accordingly, Metro began to investigate sites that were known to be contaminated and were near agency outfalls, with the intention of improving conditions.

The Denny Way CSO was chosen as an experimental demonstration cleanup project for three reasons: First, it is the largest-volume and most frequent combined sewer overflow into Elliott Bay. During wet years there can be up to 60 overflow events annually, which produce a total average overflow volume of 500 million gallons per year. Second, previous studies, including the Metro TPPS, identified a contaminated sediment problem at the site. And third, construction activities to reduce the volume of CSO overflows were not scheduled to be completed until 1999. An interim measure was considered appropriate.

Background

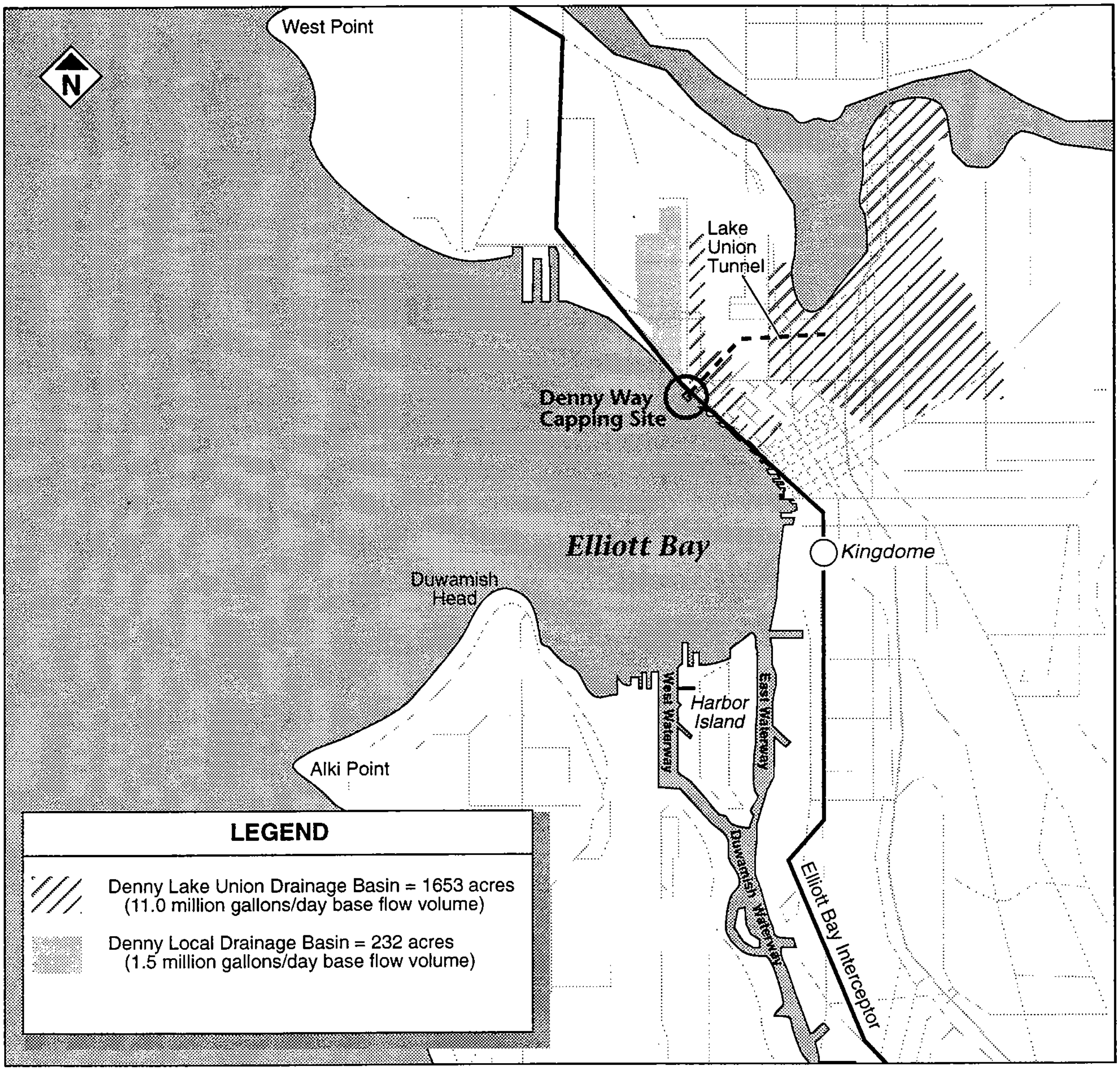
From Untreated Outfall to Source Reduction and CSO Control

The city of Seattle completed construction of two untreated sewage outfalls at the foot of Denny Way in 1895. These outfalls operated until 1969, when Metro assumed responsibility for the outfall site after the construction of the 10-foot-diameter Elliott Bay interceptor sewer line along Seattle's waterfront. The Elliott Bay interceptor was designed to capture wastewater from all sewer lines along Elliott Bay and transport it to the newly constructed West Point Treatment Plant. At this time, most sewer outfalls, including Denny Way, were converted to CSOs. During dry weather and light rain the interceptor line would continue to transport stormwater and wastewater to the plant for treatment. If the rain was heavy enough, the additional stormwater would fill up the interceptor line, blocking the flow from entering the sewer lines. The sewer line flow then would be diverted into the bay in what is call a combined sewer overflow event. About 99 percent of the overflow volume at the Denny Way CSO originates from two drainage basins called the Denny Way Local and the Denny Way Lake Union (see Map 1-2).

CATAD. In 1974, a computer augmented treatment and disposal (CATAD) system was put on-line to control Metro's wastewater collection system. The CATAD system maximizes storage in the wastewater collection network and regulates overflows. It is programmed to minimize overflows to the more sensitive freshwater bodies and give priority to discharging into marine waters. When flow reductions are necessary at the West Point Treatment plant because of emergencies or construction activities, overflows at Denny Way increase.

When the interceptor line is full but has not yet overflowed, the CATAD control raises a regulator gate to store as much volume as possible in the local wastewater pipes before diverting the flow into Elliott Bay. Storage of wastewater in local sewers at Denny Way and other regulator stations allows the interceptor line to be maintained at a full level without backing up and overflowing. When levels in the interceptor begin to drop, CATAD adjusts the regulator gates to start redirecting local flows back into the interceptor.

In 1989, CATAD was upgraded with new equipment that allowed greater control and resulted in fewer area-wide overflows. In 1993, CATAD was upgraded again to perform predictive control. Predictive control means that CATAD can anticipate stormwater entering the system based on rain gauge monitors and adjust the system in preparation. Predictive control will reduce overflows in the entire system, including some small reductions at Denny Way.



Map 1-2. Drainage Basins Contributing to the Denny Way CSO

Plan for Secondary Treatment Facilities and CSO Control. The construction of the interceptor line greatly improved conditions compared to the continuous untreated outfall that operated from 1895 to 1969. However, soon a new concern developed over whether CSO discharges were causing toxic effects in the environment. For several years, various studies were conducted around the

Denny Way CSO to look for effects on the environment (Armstrong et al., 1978; Tomlinson et al., 1980; Malins et al., 1980; Chapman et al., 1982; Comiskey et al., 1984 and Romberg et al., 1984). These studies showed that bottom sediments near the outfall contained substantially elevated levels of heavy metals and organic toxicants and that there were detectable biological effects in the form of altered benthic communities. While these studies were unable to establish a clear causal relationship between elevated chemical levels and biological effects, the strong correlation was convincing enough to indicate a need for change.

In 1986, Metro adopted a plan for secondary treatment facilities and CSO control, with a total cost of around $1 billion. Under this plan Metro must provide secondary treatment at all wastewater treatment facilities by 1995 and reduce CSO discharge volumes by 75 percent by the year 2000. Because construction of secondary treatment facilities has both the highest priority and highest cost, CSO projects will be implemented gradually. Furthermore, reducing CSO volumes in freshwater areas takes priority over marine waters. The schedule, negotiated with Ecology, is to reduce CSO flows at Denny Way to one tenth their current amount by the year 1999.

Until recently, separating stormwater from wastewater and draining the stormwater directly into receiving water was considered a viable alternative to reduce CSO overflows. However, recent studies have shown that contaminants present on streets and other impermeable surfaces are washed into the stormwater system and into the receiving waters during rainstorms. Because of this, some stormwater separation projects have been postponed to evaluate options for the treatment of stormwater before it is discharged. If stormwater treatment is necessary, it must be determined whether it is more efficient to treat stormwater separately or combined with wastewater.

With stormwater treatment in mind, there are three main options for reducing CSO volumes at Denny Way: (1) storage facilities capable of storing peak flows, (2) a primary wastewater treatment facility, (3) a combination of both. A storage facility would hold combined waste and stormwater until after a storm, when the levels in the Elliott Bay interceptor line begin to drop; then the stored wastewater would be pumped into the interceptor and transported to the West Point Treatment Plant. One option for storage would be to construct a new tunnel from the Lake Union drainage basin to the Denny Way regulator station. The new tunnel would run parallel to the existing Lake Union tunnel and increase the storage and flow capacities of the 100-year-old brick structure. A primary wastewater treatment facility would be constructed near the bay and provide primary treatment for the overflow volumes, which would then be discharged in deep water approximately 2,000 feet offshore.

Toxicant Reduction. Control options for the Denny Way CSO are very expensive and will be difficult to site, so it could take years before a major construction project could be implemented for this site. However, Metro's study, *Toxicant Reduction in the Denny Way Combined Sewer System,* conducted in 1986, explored other ways of reducing toxicant loading from this CSO source. A major part of the toxicant reduction study was to identify and control businesses that were potential pollutant sources to the Denny Way drainage basin.

Questionnaires were sent to over 500 businesses, and site visits were made to about 100 businesses to verify their situations and provide directions for proper toxicant control. Wastewater samples were taken from the sewage collection system to identify toxicant sources. Two industrial laundries in the drainage basin were found to be a major source of heavy metals. The Metro Industrial Waste Program required these laundries to install pretreatment measures that greatly reduced metals levels in the wastewater. A few illegal point sources were identified and required to change their practices to reduce toxicant inputs.

The study recommended additional source control activities and sediment capping as short-term methods to reduce toxicity in Elliott Bay. Metro implemented most of the following recommendations for source control before proceeding with sediment capping.

- Clean contaminated sediments from tributary sewer lines immediately below laundries in the area to ensure that these will not be washed into Elliott Bay.

- Remove toxic sediments from the mile-long Lake Union sewer tunnel to ensure they will not wash into Elliott Bay.

- Improve City of Seattle catch basin maintenance to reduce the input of chemically laden street dust into the sewer system.

- Modify Metro's CATAD control at the Denny Way regulator to reduce overflows from the Denny Lake Union drainage basin.

- Continue an active pretreatment program that maintains contact with permit holders and other businesses that are potential toxicant sources.

- Implement a public education program on toxicants focused on the two Denny Way drainage basins.

At Metro's request, in 1988 the City of Seattle cleaned its sewer lines immediately below several industrial laundries. The city also improved its catch basin maintenance.

Metro cleaned the Lake Union sewer tunnel in 1989. The CATAD control was modified, further reducing overflows. The Industrial Waste Section at Metro maintains a pretreatment program in cooperation with businesses that are potential sources of toxicants. A local education program was conducted as part of the toxicant reduction study. No further public education program was focused on the Denny Way drainage basin because a large-scale toxicant control education program was undertaken for the entire Seattle/King County region.

Remediation Method Selection

Several methods were considered for cleaning up the toxic sediments at the Denny Way site. A cap was determined to be the best. A sediment cap is a layer of clean sediment placed on the marine floor, isolating contaminated bottom sediments and providing a clean substrate for marine life. The term "capping" is used in this report to refer to covering sediments in place without dredging or moving them.

Alternatives to Capping. The alternative remediation methods that were considered but not pursued at Denny Way were nearshore confined aquatic disposal (CAD), offshore CAD, upland confined disposal, and natural recovery. The difference between CAD and capping is that CAD involves dredging and relocating the contaminated sediments, then covering them. Moving the contaminated sediments can release and spread toxicants. To assist Metro in the evaluation of remediation alternatives, the Elliott Bay Action Program included Denny Way as one of two sites that were addressed in the report, *Evaluation of Remedial Alternatives,* which was prepared for the Elliott Bay Action Program in 1988 by Tetra Tech.

Aquatic and upland confined disposal both involve dredging; they were not selected because of their high cost compared to capping, as well as the lack of an approved disposal area. Because no local landfills accept contaminated dredged material, upland disposal would require long hauling to a landfill out of the area. There were no approved sites in Puget Sound for either nearshore or offshore confined aquatic disposal, and it would take years to approve a site if approval were possible.

The natural recovery alternative was not selected because it means that no cleanup actions would be undertaken. Site conditions would be left to improve over time by the two natural processes of chemical breakdown and burial by accumulation of new sediment. Natural recovery is an acceptable alternative when chemical levels in the surface 10 centimeters of sediment, or the biologically active zone, will decrease below Washington State Marine Sediment Quality Standards in less than 10 years. Metals exceed the standards at the Denny Way site, however, and they do not chemically degrade over time. Preliminary information on sedimentation rates indicate that at this site it would take 20 to 60 years before 6 inches of new sediment would accumulate (Romberg et al., 1987). Consequently, natural recovery is not adequate to remediate the site.

Capping. The capping method of slowly releasing sand from a bottom-dump barge was developed under the direction of Alex Sumeri at the Corps and used for the first time in 1984 for confined aquatic disposal of contaminated dredged material in the lower Duwamish River's west waterway. The Duwamish CAD project, the oldest in Washington, has shown no evidence of chemical contaminants migrating up into the clean sand cover based on 5 years of monitoring (Alex Sumeri personal communication). Other successful Puget Sound CAD projects are at the One Tree Island Marina near Olympia and at Simpson Tacoma Kraft Company. Both are being monitored and show no signs of chemical migration into the clean sand from below.

In Puget Sound there are three in-place sediment capping projects, and all are in Elliott Bay. The first was completed in 1989 by the Washington State Department of Transportation (WSDOT) as part of the ferry terminal expansion. A 4-acre area was covered with a 1.5-foot-thick layer of sand to minimize disturbance of contaminated sediment during pier construction. The second is the Denny Way project described in this report. The third is the Pier 53-55 sediment cap, completed in 1992 and located on Seattle's downtown waterfront north of the WSDOT ferry terminal. The Pier 53-55 capping project involves 3 acres that were capped with 3 feet of sand and another 1.5 acres that were covered with about 1 foot of sand. Three feet is considered enough to isolate contaminants and allow the benthic community to start over. The 1-foot-thick area, called the Enhanced Natural Recovery Area, is an experiment to see if a thinner layer of clean sand will also support a benthic recovery while maintaining navigational depth.

THE DENNY WAY SEDIMENT CAP

The contaminated bottom sediments at the Denny Way site were capped by slow, controlled release of a clean sand blanket from a partially opened split-hull bottom-dump barge being moved sideways by a tugboat.

Many engineering considerations had to be addressed in determining the final plans for the capping site. These issues included water currents, tides, storm waves, bottom sediment characteristics, contaminants, bathymetry, future site use, groundwater, recontamination potential, types of local burrowing organisms that could compromise the cap, and the desired cap thickness. Other design considerations included volume of dredged sand available, physical and chemical properties of the dredged material, availability and cost of dredging and disposal equipment, and survey equipment the Corps had available and how it had to be modified to accomplish the required positioning. The Corps policy is to accomplish dredging projects by the least costly and most environmentally sound method.

The capped area lies in water depths between 20 and 60 feet (mean lower low datum). It is composed of two adjacent rectangular sections measuring 200 by 600 feet and 150 by 70 feet. The intended objective was to cover this 3-acre area with a uniform blanket of clean sand 3 feet thick. Thirteen barge loads, each carrying about 1600 cubic yards of sand, were spread in a systematic manner. The total volume of sand spread was almost 20,500 cubic yards. It is generally considered that the 3-foot cap is sufficient to prevent burrowing organisms from entering the underlying contaminated sediments.

Immediate Benefits

It would be preferable to eliminate all toxic discharges before capping. However, the schedule in Metro's Facilities Plan shows that the project to reduce CSO overflow volumes at Denny Way will not be finished until about 1999. There are still three primary advantages to capping contaminated sediments sooner rather than later:

- Sediment quality improves immediately instead of waiting 20 to 60 years for new sediment to accumulate through natural sedimentation. Because of reduced toxicant sources, sediment quality on the cap should remain better than pre-cap conditions.

- Historically contaminated sediments are covered up so it is easier to identify current pollutant inputs by monitoring any recontamination at the cap surface. Then the effort can focus on eliminating these sources.

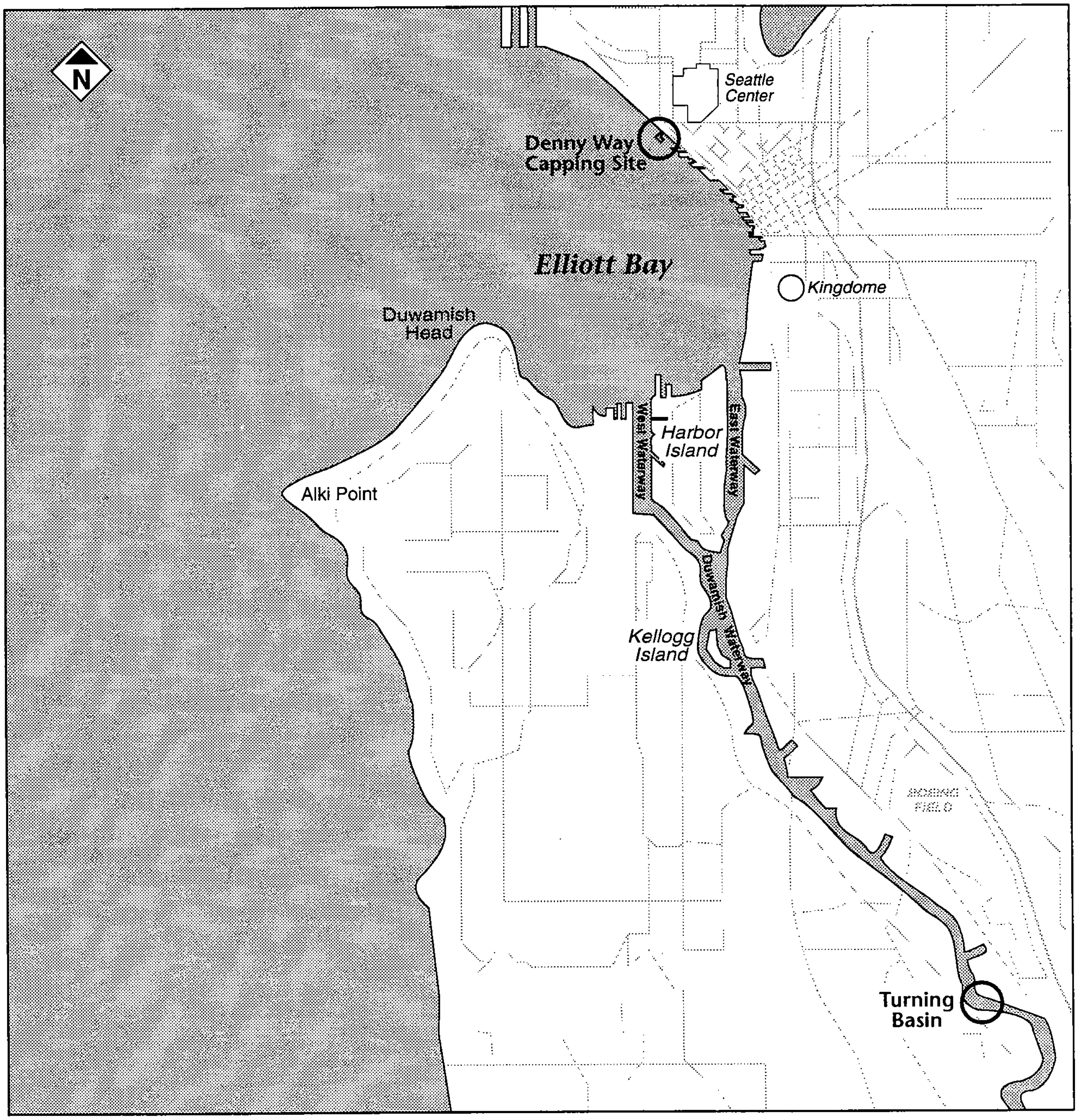
- Information and experience are provided that will expand our understanding of capping as a tool for improving environmental conditions in Puget Sound.

Source of Sediment

A dredge contractor for the Corps dredged clean sand from the upper Duwamish River during routine maintenance for navigation (see Map 1-3). The cooperative capping project evolved mainly because the Corps is interested in using clean dredged material for beneficial purposes. However, the Corps must be able to dispose of this material in the least costly manner and in a way that is environmentally acceptable. The cheapest acceptable method is to take it to the Puget Sound Dredged Disposal Analysis (PSDDA) open water disposal site in Elliott Bay. Using this as a cost baseline, the Corps agreed to dredge, transport, and place clean sediments at Denny Way; in return Metro agreed to conduct sediment tests on the dredged material. Metro, acting as project sponsor, signed an agreement to "hold and save the Corps harmless" from issues that arise after cap placement.

Monitoring Plan

Environmental monitoring for the project included short-term activities needed for cap placement and long-term activities documenting how well the cap functions. The long-term strategy called for intensive sampling and observation during the first few years after capping, followed by less frequent monitoring as appropriate. A 5-year plan was adopted and is currently underway. Monitoring will continue for 2 more years, at which time future requirements will be determined after review and discussion by the permitting agencies. A summary of the sampling activities and schedule is provided in Table 1-1.



Map 1-3. Duwamish River Dredge Site and Denny Way Capping Site

TABLE 1-1. Summary Schedule of Monitoring Activities for the Denny Way Capping Project								
	5-Year Plan Confirmed							
	During capping 1990	1990	1991	1992	1993	1994	1995	After 1995
Water column samples	X							
Bathymetric surveys, diver surveys	X		X[c]	X[c]		X	X[c]	
Sediment cores for chemistry (3 sites, 5 sections)		X[a]	X	X		X		?
Surface grabs for chemistry (5 sites, top 2 cm)		X[a]	X	X		X		?
Surface grabs for taxonomy (3 sites, 5 replicates)		X[b]	X	X		X		?
REMOTS sediment-profile camera survey			X					
Video camera survey		X						
Monitoring report		X	X	X		X		
Monitoring review meetings		X[b]	X[b]	X[b]		X[b]		
Five year project review							X	2000

a) Baseline sampling within the first 2 months after cap placement.
b) First-year taxonomy samples stored until need for analysis determined.
c) One of the survey methods will be used within the indicated time period.
d) Meetings may be held within the first 2 months of subsequent year.

In the first year of the plan (1990), monitoring was conducted but a report was not submitted because of a lawsuit brought by the National Oceanic and Atmospheric Administration against the City of Seattle and Metro. Staff time was used instead to prepare depositions. Alex Sumeri of the Corps and Pat Romberg of Metro, however, submitted a paper and gave a talk to the permitting agencies after the first year's monitoring was completed.

PERMITS

With Corps technical assistance, Metro obtained the necessary permits and addressed issues raised by the Washington Environmental Council, Muckleshoot Indian Tribe, Washington Department of Natural Resources, and others. The

Permits

Corps substantially complied with the regulatory requirements of the Clean Water Act Section 404 process for the dredging of sediment used as capping material and arranged for all sediment sampling needed to satisfy the Puget Sound Dredged Disposal Analysis requirements for determining whether the sediments were suitable for capping material. Metro, as sponsor, obtained all the permits capping. Table 1-2 lists the permits required, the granting agency, and some of the conditions addressed.

TABLE 1-2. List of Permits

Permit(s)	Agency	Condition(s)
Shoreline Substantial Development	City of Seattle	Oil spill containment plan required; must stop work if any fish were observed to be in distress; approval of other agencies required.
1. Water quality certification 2. Short-term water quality exemption	WA Dept. of Ecology	Dredged sediment quality; dissolved oxygen criteria; fish distress clause; debris and spill clauses.
Hydraulic Project Approval	WA Dept. of Fisheries	Monitoring report; operations window; disallows rocks; fish distress clause; no siltation or debris allowed.
Leasing agreement	WA Dept. of Natural Resources	Monitoring plan and reports.
1. Section 10 2. Section 404	U.S. Army Corps of Engineers	Reviewed and approved monitoring plan.

SECTION 2

PRE-CAP STUDIES

Several studies of the Denny Way CSO marine sediments and a study of the pre-dredge Duwamish River sediments contributed needed information to the Denny Way capping project. This section summarizes five studies: *Fate and Effects of Particulates Discharged by Combined Sewers and Storm Drains* (Tomlinson et al. 1980), *Toxicant Pretreatment Planning Study* (Comiskey et al. 1984 and Romberg et al. 1984), *Toxicant Reduction in the Denny Way Combined Sewer System* (Romberg et al. 1987), Waterfront sediment studies in 1988 and 1989, and a study of the pre-dredge Duwamish River Sediments in 1989.

FATE AND EFFECTS OF PARTICULATES DISCHARGED BY COMBINED SEWERS AND STORM DRAINS

In 1980, Tomlinson et al. completed the study *Fate and Effects of Particulates Discharged by Combined Sewers and Storm Drains* for the Environmental Protection Agency. The study investigated the fate and ecological effects of particulates in stormwater runoff and combined sewer discharges entering Lake Washington from several outfalls and in the discharges entering Puget Sound from the Denny Way CSO. The following summary is focused on the information gathered at the Denny Way CSO.

Methods

The Denny Way CSO was sampled for loading analysis of suspended solids, metals, total organic carbon, total phosphorus, oils and grease, and total chlorinated hydrocarbons. Water samples were collected at regular intervals during overflow events. Outfall plume distributions were measured using a light transmission meter on a grid of 42 stations. In situ bioassay studies were conducted using the mussel *Mytulis edulis* and the oyster *Crassostrea gigas*. Two hundred individuals of each species were placed among four crab pots and were anchored at various distances from the CSO. Intertidal benthic organisms were sampled using Plexiglas cores 15 centimeters deep. Subtidal benthic organisms were sampled using a 0.1-square-meter Van Veen grab sampler.

Results

The area 200 to 300 meters along the shore in both directions from the outfall was measurably affected by settling particulates. Surface sediments near the outfall showed evidence of heavy inputs of CSO particulates. Studies of the local aquatic biota showed that the nearshore area within 150 meters of the CSO could be referred to as polluted. The relative effects were evident at the 9-meter depth contour, but diminished offshore at the 13-meter depth level. There was some evidence that the shallow subtidal infauna underwent a small degree of recovery during periods of few overflows.

The mean concentrations of heavy metals in both the particulates and the particulates-plus-soluble wastes that were discharged at Denny Way were greater than comparable discharges in Lake Washington, reflecting the large component of industrial and commercial inputs to the Denny Way system. However, the mean concentration of chlorinated hydrocarbons in particulates at Denny Way was much lower, implicating residential use as the principal source of pesticides.

TOXICANT PRETREATMENT PLANNING STUDY

In 1984 Metro completed the *Toxicant Pretreatment Planning Study* (TPPS), a multiyear effort designed to provide basic information and answers concerning local toxicant issues. TPPS contained 15 separate reports.

Two of the TPPS reports are summarized in this section. *Presence, Distribution and Fate of Toxicants in the Puget Sound and Lake Washington* (Romberg et al. 1984) is an analysis of the occurrence of toxicants in receiving waters, sources of toxicants, transport, and deposition. *Puget Sound Benthic Studies and Ecological Implications* (Comiskey et al. 1984) is an analysis of biological testing of bottom sediments in Puget Sound, correlated with toxic loadings.

Presence, Distribution and Fate of Toxicants in Puget Sound and Lake Washington

One of the goals of the TPPS was to determine the status of toxic chemicals in Puget Sound and Lake Washington as a basis for making facility planning decisions regarding toxicant removal. Romberg et al. reported on that investigation. This summary deals with the part of the toxicant study that relates to the Denny Way CSO, Elliott Bay, and Puget Sound. Chemistry data tables appear in Appendix B.

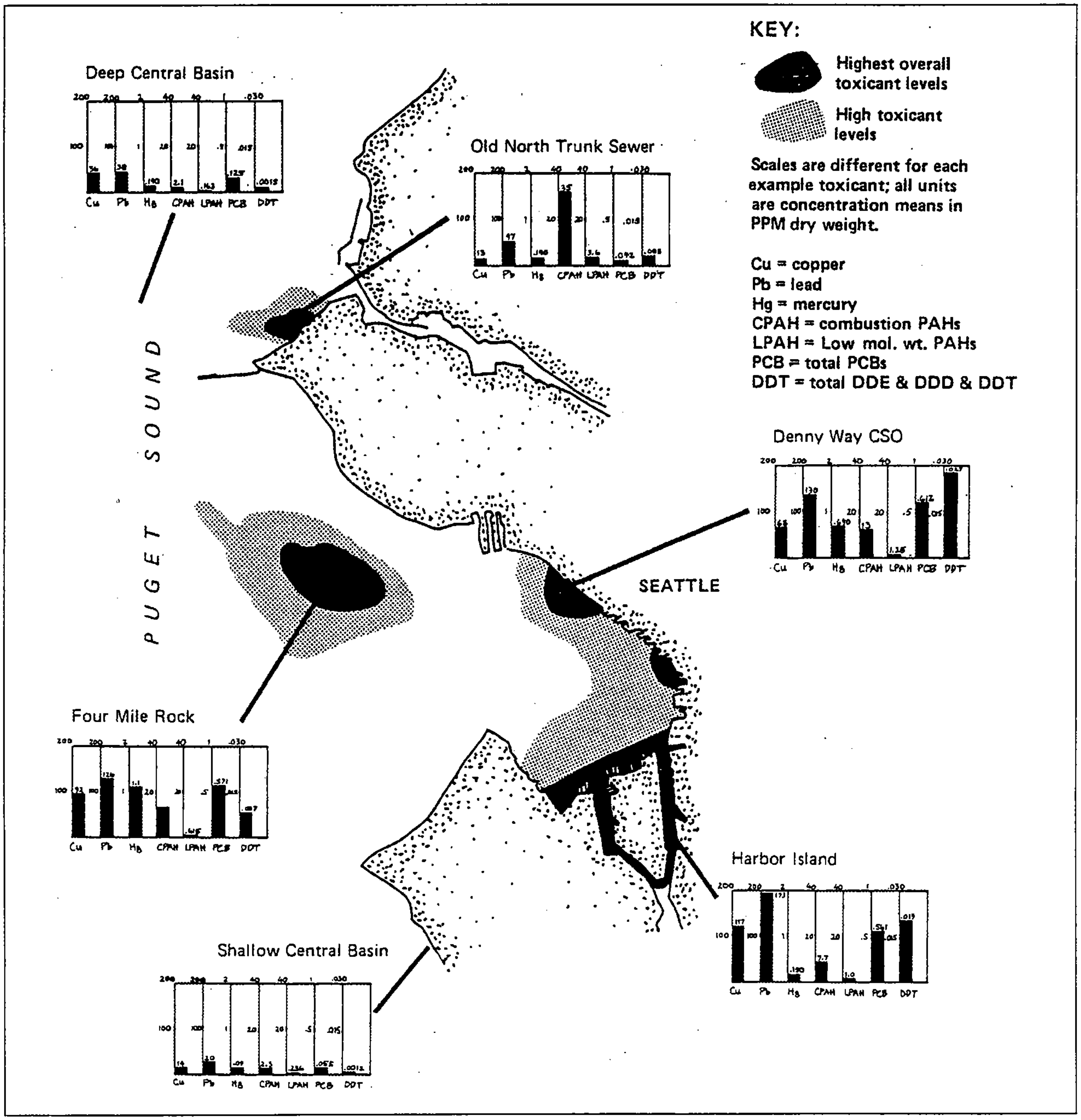
Methods. The data generated in this study were obtained during an intensive two-year field survey initiated in the winter of 1980–81. Sampling resolution was enhanced in central Puget Sound specifically near urban areas and regions receiving major point source discharges.

Sediment samples were collected with a (galvanized) modified Van Veen grab sampler. In addition to grab samples, sediment cores were also collected using Kasten cores. The samples were tested for the 125 chemicals on the EPA Priority Pollutant List.

Results. While far more priority pollutants were found in sediments than in water and particulates, still about 40 percent of the 125 priority pollutants were never detected in the sediments. Overall, a total of 70 priority pollutants were detected at least once, and about half of these were seen frequently. These frequently detected chemicals include all the metals except thallium, most phthalates, low molecular weight PAHs, high molecular weight or "combustion" PAHs (CPAHs), and the pesticide DDE.

Contour maps of sediment concentrations were developed from this study's numerous sediment samples, which provided a clear picture of the spatial distribution of toxicants in central Puget Sound. A summary of Puget Sound sediment chemistry is shown in Map 2-1. Concentrations in the main basin were generally low near shore and tended to increase to medium levels along the bottom of the deep central basin. This trend corresponds well to average grain size, with coarser sediments in the shallow and sloping regions and finer silts in the deep central basin. A few areas had distinctly elevated levels that were related to local influences: the entire waterfront of Elliott Bay including the Denny Way CSO and the Duwamish; the Four Mile Rock dredge spoils disposal site off Magnolia Bluff; and a small nearshore area between West Point and Shilshole Bay where the old North Trunk raw sewage outfall discharged before Metro was formed. Elevated levels in these areas gradually decrease with distance toward the deep central basin, where inputs from numerous sources all tend to blend together and concentrations typically are medium to low.

True background concentrations in deep basin sediment prior to industrialization were determined from sediment cores. Among metals, lead showed the highest level of increase—six times above historic background. It appeared, however, that these concentrations have been fairly stable for two or more decades and even have shown some decrease in recent years.



Map 2-1. TPPS Summary of Puget Sound Sediment Chemistry

While there were no established sediment criteria for evaluating observed concentrations, the levels found in Puget Sound were compared with concentrations in other areas. Concentrations in the main basin tended to fare well in such comparisons, while high values in Elliott Bay often exceeded many of the reported levels from other urban areas, and were surprisingly close to concentrations found in such places as the heavily polluted Houston Ship Canal. These comparisons, and the fact that fish disease and altered benthic communities occur in Elliott Bay and the lower Duwamish River, where there are important biological resources, led to the conclusion that sediment chemical concentrations in these areas are a problem.

Puget Sound Benthic Studies and Ecological Implications

An important aspect of the TPPS was to determine what effect, if any, the West Point treatment plant outfall and the Denny Way CSO were having on the marine environment. The primary method used for evaluating biological effects was examination of benthic community structure, with a secondary emphasis on laboratory bioassay tests and priority pollutant concentrations in edible seafood. Comiskey et al. reported this investigation. This summary deals with the part of the study relating to the Denny Way CSO.

Methods. Benthic studies were conducted in three phases, as follows:

Phase I — Pre-sampling review of previous study results to enable the design of a Phase II reconnaissance sampling plan.

Phase II — Reconnaissance sampling of taxonomy and environmental variables at 70 stations in the study area to provide the required information to design an intensive Phase III toxicant impact study.

Phase III — Detailed study of taxonomy, priority pollutants, and environmental variables at 26 stations during two seasons—Wet Season (Phase IIIA) and Dry Season (Phase IIIB)—to determine whether toxicant-related effects exist.

Biological samples were taken during wet and dry seasons for comparison because the number of overflows and the amount of discharge increase significantly in the winter.

Samples for biological studies were collected using a 0.1-square-meter Van Veen grab sampler. Two replicate samples were collected at each station for Phase II sampling and four replicate samples were collected for Phase III.

Biological grab samples were screened through 1-millimeter mesh sieves to remove fine sediments. The remaining material (organisms and debris) was then placed in internally labeled bags and fixed in a solution of 10 to 15 percent sodium-borate-buffered formalin in seawater.

Community Structure. In the vicinity of the Denny Way CSO, several distinct trends were apparent that were most likely related to CSO discharges. These included higher concentrations of oil and grease and higher biochemical oxygen demand (BOD) values for the coarser-textured samples in the immediate vicinity of the outfall, along with reduced species diversity in these same samples. In general, the concentration of these carbon indices (oil and grease, BOD, volatile solids) was found to be less in the deeper, finer-textured samples in Elliott Bay, a trend that strongly indicated influence from the CSO. The values for community parameters (such as abundance and diversity) at all the Elliott Bay stations were typically lower than those at comparable depths in the central basin; however, this may have been partly due to textural differences, since for a given depth the Elliott Bay samples were always finer in texture than the central basin samples.

Members of one of the groups of taxa showed a preference for the stations in the immediate vicinity of the Denny Way CSO. These included the polychaete worm *Capitella capitata*, a known indicator of organic enrichment. Other taxa showed the opposite trend, apparently avoiding the shallow area near the CSO. These included the sensitive amphipod family Phoxocephalidae, which have been used for sediment bioassay tests.

Based on biological community structure analyses, the Denny Way CSO was unquestionably having a detrimental effect on the organisms in the immediate vicinity of the outfall, out to at least 30- to 40-meter depths. It is difficult to attribute pollutant effects to any particular source in an area with numerous inputs, but those around the Denny Way CSO were fairly distinct. The effects appeared to be local in nature, and the CSO did not appear to be contributing substantially to the toxicant burdens in the rest of Elliott Bay.

Bioassay Results. Various bioassay tests were conducted in an attempt to directly measure toxicity or toxic responses in locally collected sediment samples. The tests, while the best available at the time, were still in various stages of development. The results obtained were mixed and inconsistent. No firm conclusions regarding priority pollutant impacts can be drawn from the bioassay data, but the results illustrate the attempt made to use these techniques for assessing toxicant problems.

The results of the amphipod bioassay tests indicated that sediments at a substantial number of stations in the study area were potentially toxic to sensitive marine organisms. However, more rigorously conducted follow-up amphipod bioassays in a second phase did not show this high degree of acute lethality, with only 40 percent of the Denny Way stations yielding a response. The two stations located closest to the CSO were highly contaminated and showed a response, but other highly contaminated stations showed no response. In general, the amphipod bioassay tests showed no consistent relationship between amphipod mortality and concentrations of priority pollutants

Initial oligochaete respiration tests conducted at the Denny Way stations indicated a biological stress response of 40 percent. Further data analysis provided little help at identifying what caused the response and showed there was no correlation between the bioassay response and the priority pollutants measured at the same site. No stress response occurred at the most highly contaminated sites nearest the CSO, but responses occurred at stations farther away with much lower concentrations of metal, organic, and conventional pollutants.

TOXICANT REDUCTION IN THE DENNY WAY COMBINED SEWER SYSTEM

In May 1986, Metro began a trial program aimed at identifying and reducing toxicants going into the sewer system that is tributary to the Denny Way CSO. The program was an interim approach to improving environmental conditions at Denny Way before new construction could reduce the level of discharge. The Metro Facilities Plan, adopted in 1986, includes many large construction projects that will provide secondary treatment and reduce CSO volumes. However, construction of secondary treatment facilities has the highest priority, with the result that construction of the CSO projects must be distributed over time.

The Denny Way CSO was chosen for this program because it is the largest CSO discharging to Elliott Bay and it was identified as a major source of substantially elevated levels of toxicants in bottom sediments.

Methods

This study included the following activities:

- Identified all commercial businesses that use potentially toxic chemicals and are in the tributary system of the Denny Way CSO.
- Conducted a survey designed to provide information about the types and volume of wastewater discharged from these commercial sources.
- Sampled sediment in the sewer system to detect chemicals and identify sources.
- Conducted site inspections of representative businesses in the study area.
- Sampled offshore sediments to document existing contamination levels for future comparison of change over time.

Results

Study activities were divided into two major parts: an investigation of commercial sources of toxic chemicals and a study of sediments offshore of the CSO.

Commercial Source Control. Nearly all the wastewater that overflows at the Denny Way CSO originates in two drainage basins, the Denny Lake Union Basin and the Denny Local Basin, with a total area of 1,885 acres. The Denny Lake Union Basin is about seven times larger than the Denny Local Basin and has more commercial sources. A total of 530 businesses were identified as potential toxicant sources in these basins, including a large number of print shops and photo/design businesses. Response to questionnaires in this basin was especially good. It showed that only a small number of these businesses had any nonsanitary discharges, and their combined volume was only about 4 percent of the average base sanitary flow of 12.6 million gallons per day.

Site visits were conducted at 96 businesses to verify the discharge volumes. A need for better storage, housekeeping, and spill prevention practices was identified at many sites. Letters with specific directions for improvements were sent to

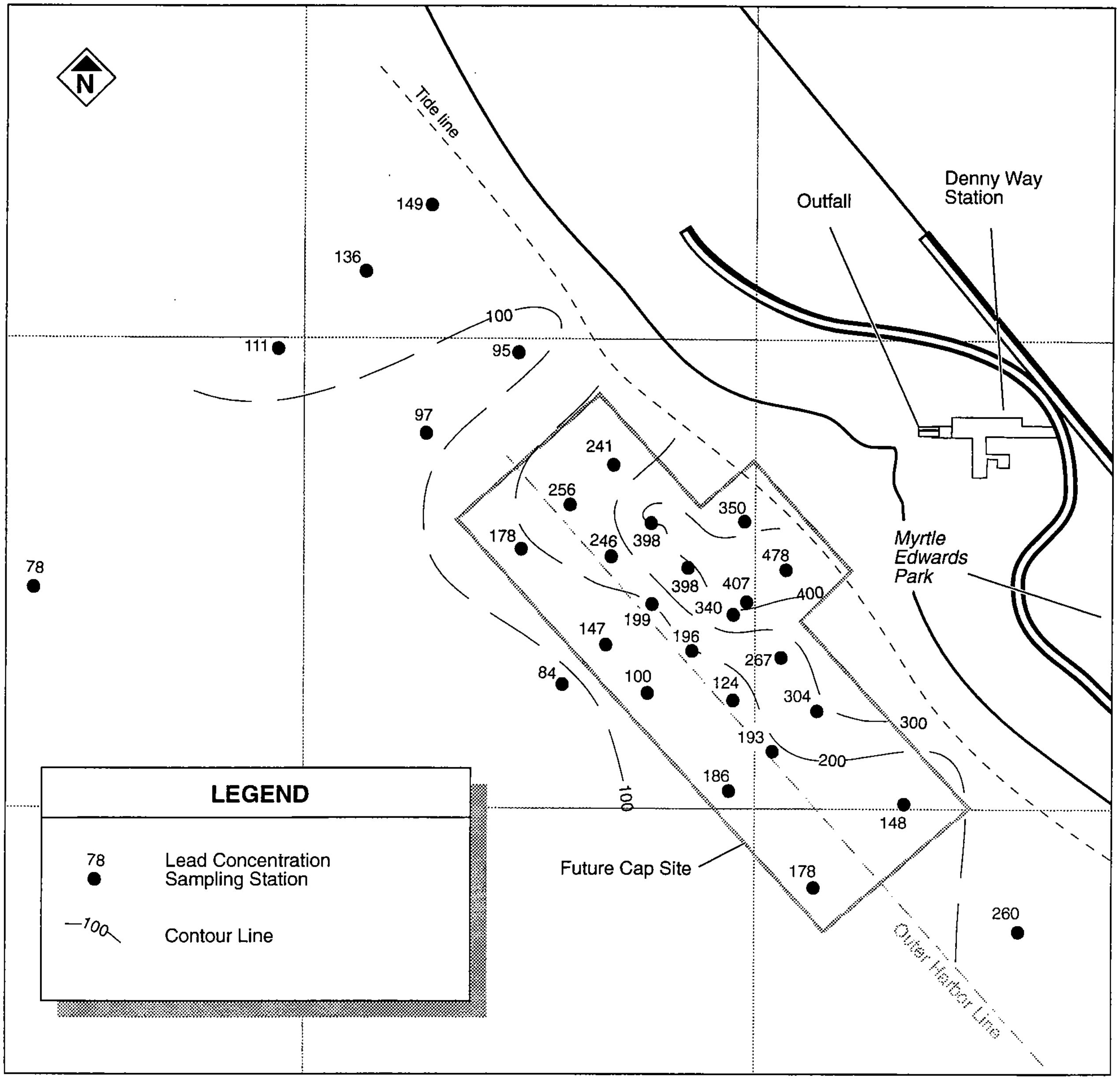
40 businesses. Site visits also helped identify previously unknown sources that were indicated by the collection system samples. These sources have either been eliminated or required to obtain a Metro industrial waste permit.

Two laundries, which had been regulated through existing permits, were the most identifiable sources of metals and volatiles organics in the collection system samples. Installation of new pretreatment equipment produced documented improvements in discharge concentrations. The large discharge volumes from these sources, however, have a measurable impact downstream in the collection system. A large accumulation of sediments in the Lake Union Tunnel was found to contain high concentrations of metals that appear to be linked to historic inputs from these laundries. These sediments can wash out of the Lake Union Tunnel and into Elliott Bay through the Denny Way CSO and may be responsible for high metals levels in the offshore environment.

PCBs and CPAHs were also found in the tunnel sediment samples. PCBs were only found in one sample, while high levels of CPAHs were found and appear to be linked to street runoff.

Besides controlling commercial sources, there may be a few changes in the collection system facilities that could reduce the toxicant loading discharged from the Denny Way CSO. Special catchment structures could possibly be used to increase in-line sedimentation of the heavier contaminated particles at preferred locations where they can be cleaned out on a regular basis. The computer augmented treatment and disposal (CATAD) system controls could be modified to maximize containment of flows from the Denny Lake Union Basin, since this basin contributes the largest loading. Total flow volume from the Denny Lake Union Basin could be significantly reduced if flows from about one-third of the service area could be diverted back into the Dexter Tunnel.

Offshore Sediments. Offshore sediment samples from a grid of 29 stations showed that surface sediment concentrations for organic pollutants were far more variable than metals values, both in terms of range of values and distribution patterns (see Map 2-2). Chemical concentrations decrease more rapidly with distance offshore (increasing depth) than they do with distance along shore. Despite certain anomalies, the general distribution pattern tends to be fairly symmetrical both north and south of the outfall structure. Cluster analysis of metals data was used to define groups of stations with similar conditions. There was still so much variability within the groups that concentrations of metals in these sediments would need to change 20 to 30 percent before this change could be



Map 2-2. 1986 Distribution of Lead Concentrations in Surface Sediments

verified statistically. Because organics data were more variable than metals data, there would need to be an even larger change in organics level before the difference could be detected with a sample size of 5 to 15 stations.

There is some similarity in the distribution patterns of related groups such as LPAH and HPAH compounds. Both tend to decrease with distance from the outfall. PCB values varied entirely independent of PAH values and failed to show any consistent distribution pattern. The two highest PCB concentrations were on either side of two stations where no PCBs were detected. It is tempting to attribute this difference to analytical error, but the chromatograms were reviewed and the chemist confirmed that no PCBs were detected at these two locations, which are both near the outfall.

Sedimentation rate is an important factor that influences how fast pollutants build up in the environment and also how fast concentrations decline when the pollutant source is removed. To determine sedimentation rates, sediment cores were collected at four offshore stations. A total of 20 one-centimeter-thick layers from each core were analyzed. This analysis showed that copper and lead concentrations, starting with the deepest layer and moving up, increased for several layers and then decreased abruptly. This abrupt decrease or peak in concentrations appeared to be associated with the construction of the Elliott Bay interceptor and the Denny Way regulator in 1969. The interceptor and regulator divert continuous wastewater flows to the West Point treatment plant. When this peak is used to age-date the two sediment cores closest to the outfall, the calculated sedimentation rates are 1.4 centimeters (cm)/year and 0.7 cm/year. The natural sedimentation rate without the outfall is estimated at only about 0.25 cm/year. At this rate, it would take 10 years to accumulate only 1 inch of new overlying sediment and 60 years to accumulate one-half foot.

One method of speeding up the natural "capping" process is to artificially spread clean sediment over the area. Ideally it would be preferable to eliminate the pollutant source before capping, but in some cases it may still be practical to cap sediments before the source is eliminated. The two primary benefits of capping at the Denny Way CSO would be the following:

- Sediment quality improves immediately instead of waiting 20 to 60 years for new sediment to accumulate. And because of reduced toxicant sources, sediment quality on the cap should remain higher than pre-cap conditions.

- Historically contaminated sediments are covered up, so it is easier to identify current pollutant inputs and focus on eliminating them.

This report concluded with the following ten recommendations:

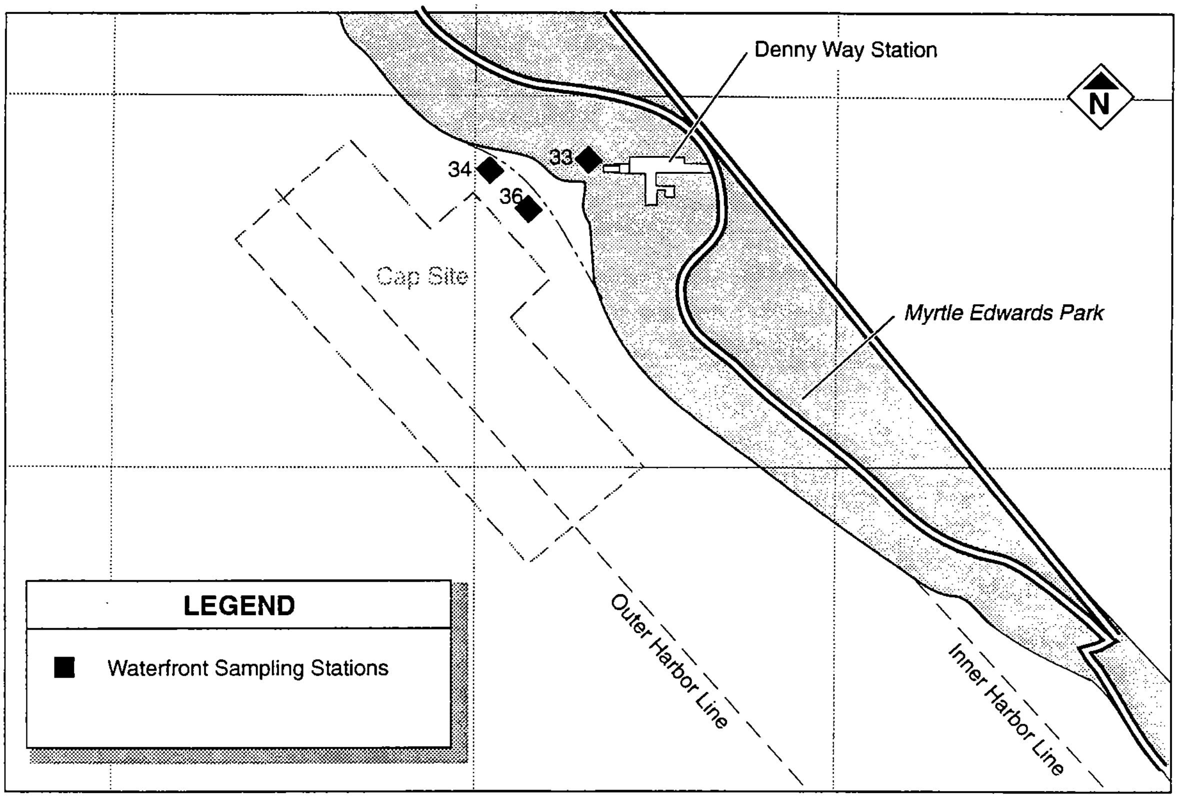
- Remove contaminated sediments from the Lake Union Tunnel to ensure they will not wash into Elliott Bay.
- Determine whether sewer lines immediately downstream of laundries should be cleaned, and establish a schedule for cleaning.
- Develop methods to increase in-line sedimentation at convenient cleanout sites so that contaminated sediment can be removed before reaching the CSO site.
- Improve maintenance of catch basins to reduce input of street dust into the sewer system.
- Modify CATAD control at the Denny Way Regulator to reduce overflow from Denny Lake Union Basin.
- Continue an active pretreatment program that maintains contact with permit holders and other businesses that are potential toxicant sources.
- Implement a public education program on toxicants focused on the two Denny Way drainage basins.
- Apportion the estimated total toxicant loading among probable sources to help determine their relative importance.
- Evaluate diverting flow from about one-third of Denny Lake Union Basin back into the Dexter Tunnel.
- Cap the contaminated offshore sediments with a layer of clean sediment.

WATERFRONT SEDIMENT STUDIES: 1988 AND 1989

Metro collected intertidal sediment samples near the mouth of the Denny Way CSO in 1989 (see Map 2-3). These intertidal samples provided background data for the capping project, confirmed the sediment quality findings of previous studies, and showed shoreline conditions relative to offshore conditions. Chemistry data appear in Appendix B.

Methods

Researchers collected samples from the beach at low tide at intertidal stations 33, 34, and 36. Samples were collected by inserting a 2-inch-diameter stainless-steel coring tube into the sediment to a depth of 6 centimeters. Four to six cores



Map 2-3. 1988 Waterfront Intertidal Sampling Stations

were collected at each station, placed in a 4-liter beaker that had been cleaned in a muffle furnace at 500°C, and homogenized with a teflon stir bar. Subsamples were placed in cleaned containers and analyzed for metals, organic priority pollutants, and particle size distribution.

Results

Nineteen semi-volatile compounds were found above detection limits at Station 34 (see Table 2-1). At Station 36, sixteen compounds were above detection limits. Aroclor 1254 (a PCB) was above detection limits at both stations. Of the semi-volatiles, fluoranthene was found in the highest concentrations at both stations: 2,900 parts per billion (ppb) at Station 34 and 1,800 ppb at Station 36. The compound with the next highest concentration was phenanthrene: 1,900 ppb at Station 34 and 1,400 ppb at Station 36. Pyrene was found at 1,700 ppb at Station 34 and 840 ppb at Station 36. Aroclor 1254 was in highest concentrations at Station 36 at 850 ppb. It was found at 240 ppb at Station 34.

DUWAMISH RIVER SEDIMENT STUDY

As part of the routine maintenance of keeping the Duwamish waterway open and navigable, the Corps dredges sediment and barges it to the PSDDA open water disposal site in Elliott Bay. For sediment to be eligible for disposal at the PSDDA disposal area it must be tested and pass PSDDA disposal guidelines for dredged sediments. All testing concerning the suitability of the dredged material for the Denny Way capping project was based on the PSDDA procedures and standards for unconfined, open-water disposal of dredged material.

PSDDA procedures (Evaluation Procedures Technical Appendix PSDDA 1988b) were developed by an interagency committee, the Evaluation Procedures Work Group (EPWG), composed of representatives from each of the PSDDA agencies: Ecology, the Corps, EPA, and DNR. Representatives from other federal and state agencies, Puget Sound ports, Indian tribes, and the public also assisted EPWG. The goal of PSDDA is to provide publicly acceptable guidelines for environmentally safe, unconfined, open-water disposal of dredged material, and to provide Puget Sound-wide consistency and predictability in decisions concerning dredged material disposal.

TABLE 2-1. Detected Chemicals at Waterfront Sampling Stations

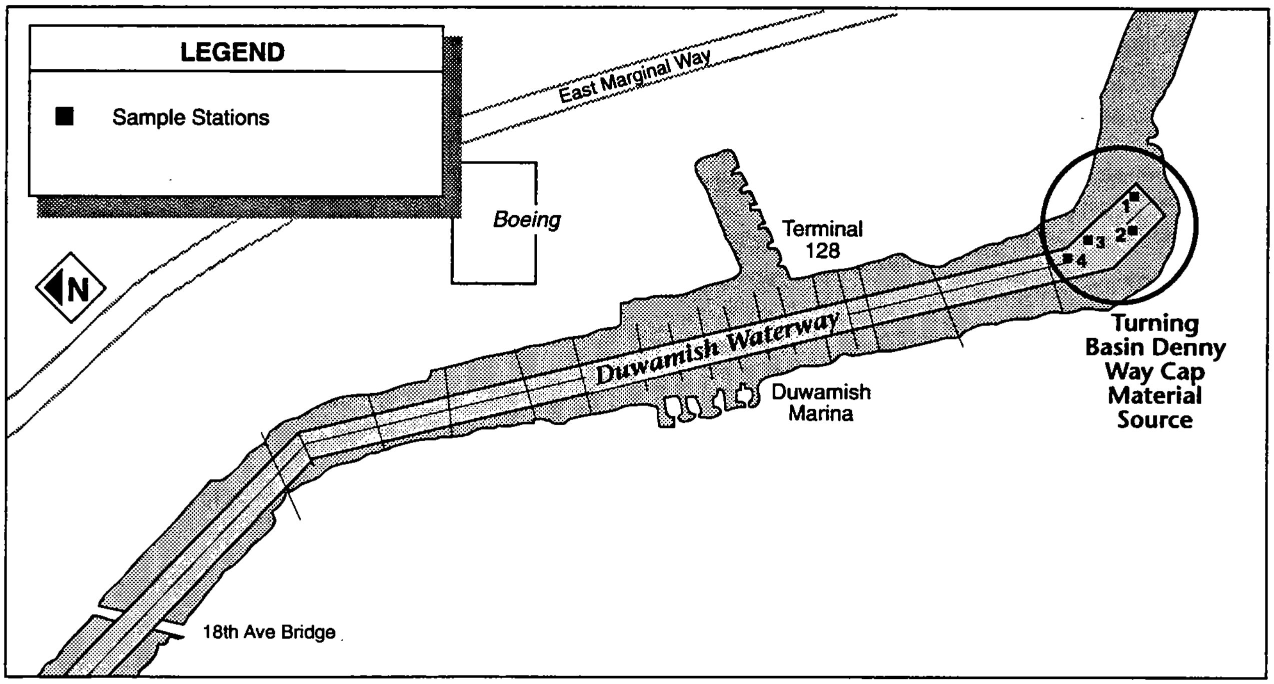
Station Locator	Station 33 LTBD19				Station 34 LTBD20				Station 36 LTBD22			
Date Sampled	Jun 29, 88				Jun 29, 88				Jun 29, 88			
Sample Number	8807391				8807392				8807394			
% Solids	82				78				80			
BNA Organics (µg/kg dry weight)	**Value**	**Qual**	**MDL**	**RDL**	**Value**	**Qual**	**MDL**	**RDL**	**Value**	**Qual**	**MDL**	**RDL**
LPAHs												
Acenaphthene	61		9	16	190		9	17	190		9	16
Acenaphthylene		<MDL	10	21	35		10	22		<MDL	10	21
Anthracene	94		10	21	290		10	22	230		10	21
Fluorene	70		10	21	220		10	22	200		10	21
Phenanthrene	650		10	21	1900		10	22	1400		10	21
HPAHs												
Fluoranthene	1100		10	24	2900		10	26	1800		10	25
Pyrene	520		10	21	1700		10	22	840		10	21
Benzo(a)anthracene	260		10	21	860		10	22	340		10	21
Chrysene	320		10	21	990		10	22	500		10	21
Benzo(b)fluoranthene	200		40	61	600		40	64	210		40	63
Benzo(k)fluoranthene	200		40	61	600		40	64	210		40	63
Benzo(a)pyrene	230		20	40	680		30	42	240		30	41
Dibenzo(a,h)anthracene		<MDL	40	61	120		40	64		<MDL	40	63
Indeno(1,2,3-Cd)Pyrene	89		20	40	280		30	42	100		30	41
Benzo(g,h,i)perylene	85		20	40	270		30	42	100		30	41
Other BNA												
Benzyl Butyl Phthalate		<MDL	10	21	550		10	22	250		10	21
1,4-Dichlorobenzene		<MDL	10	21	100		10	22		<MDL	10	21
Benzoic Acid	150		60	120	150		60	130	150		60	130
Benzyl Butyl Phthalate		<MDL	10	21	550		10	22	250		10	21
Dibenzofuran	40		20	40	130		30	42	120		30	41
PCBs (µg/kg dry weight)												
Aroclor 1254		<MDL	100	200	240		100	210	850		100	200
Metals (mg/Kg dry weight)												
Mercury	0.55	E			1.3	E			0.54	E		
Antimony	0.49	E			2.2	E			1.4	E		
Thallium	0.09	E				<MDL,	0.06			<MDL,E	0.06	
Arsenic	8.7	E			5.3	E			16	E		
Selenium		<MDL,E	0.06			<MDL,	0.06			<MDL,E	0.06	
Aluminum	7800	E			9100	E			7000	E		
Barium	22	E			74	E			24	E		
Beryllium	0.24	E			0.26	E			0.13	E		
Cadmium	1.6	E,L			2.6	E,L			1.4	E,L		
Chromium	27	E			53	E			36	E		
Copper	400	E,B			240	E,B			160	E,B		
Iron	13000	E			15000	E			11000	E		
Lead	290	E			210	E			300	E		
Manganese	180				190				160			
Nickel	35	E			46	E			30	E		
Silver	6.6	E			12	E			6.5	E		
Zinc	180	E,L			260	E,L			250	E,L		

<RDL - Detected below quantification limits
<MDL - Undetected at the method detection limit
B - Blank contamination
G - Low standard reference material recovery
L - High standard reference material recovery
E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

The sampling procedure developed by PSDDA to evaluate sediments is tiered. Tier 1 is an evaluation of the project area to determine if the sediments may contain chemicals of concern. If sediments are suspected to contain chemicals of concern, then chemical testing is required (Tier 2). Biological testing (Tier 3) is generally required only if chemical concentrations fall within a certain range above a screening level and below a maximum allowable level (Ecology 1989).

With the Denny Way sediment capping project in mind, the Corps identified specific sediment sampling sites in the turning basin of the upper Duwamish River where historically the cleanest sediments have accumulated and where they have been dredged for use as capping material (Sumeri 1991, Sumeri and Romberg 1991) (see Map 2-4). In the turning basin area, 10 to 15 feet of sand accumulates approximately every 2 years. To test the sediments that are to be dredged, vertical cores must be taken through the deposit to adequately characterize the sediment's chemical makeup.

Approximately one year prior to dredging, the sands were analyzed for volatile organics, semivolatile organics, pesticides, PCBs and nine metals. One core was taken from each of four stations at the dredge site. Since the dredging operation would mix sand from all four stations, one could expect the cap to be homogeneous. Chemistry data appear in Appendix B.



Map 2-4. Duwamish River Sampling Stations

Methods

The Corp's shore-based survey crew positioned the sampling vessel *Puget* to within ±3 meters of the sampling station site by using a laser theodolite range/azimuth positioning system following a prism mounted on the side of the vessel. The survey crew used local Corps benchmarks, established from U.S. Coast and Geodetic Survey benchmarks, for horizontal control. Surveyors directed the captain to the desired location over the ship's radio. Once over the station site, surveyors recorded the range and azimuth and directed the crane operator to quickly lower the sediment core sampler.

The Corps sampled the Duwamish sediments by using a crane-operated vibracore aboard the sampling vessel. A vibracore is a metal tripod stand that supports a pneumatic-driven vibrating device positioned on top of a coring device. The coring device is a hollow steel pipe that is fitted with a Lexan tube for each sample. Vibracore operators lowered the device into position and turned on the air compressor. The vibrator vibrated the coring drill into the sediment. After the core sampler reached the appropriate depth—in this case 14 feet—the operators turned off the air supply and hoisted the vibracore onto the deck of the sampling vessel for processing.

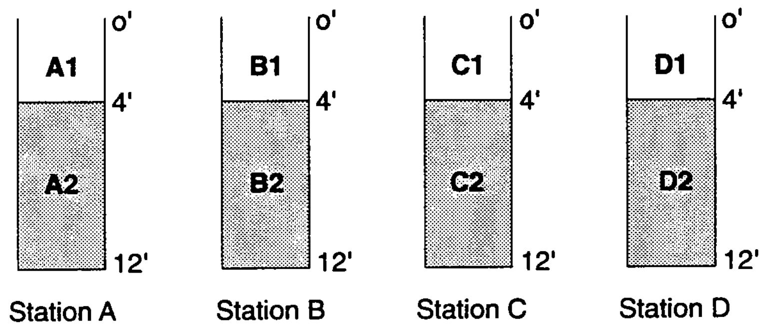
On board the research vessel, field personnel removed the Lexan tube containing the sample and placed it on a cutting trough. They gently drained excess seawater from the top of the Lexan tube, measured the length of the core sample, scored the tube with a power saw, and cut it open with utility knives, taking care not to introduce Lexan shavings into the sample. The technicians then sliced the core sample lengthwise to expose the center of the sample.

Sections of the four cores were combined to form composite samples representing the top 4 feet (0-4 ft depth) and the bottom 8 feet (4-12 ft depth). There were two composite samples representing each of these depths. Figure 2-1 is a schematic of the core divisions.

Results

As many as 15 semivolatile organic compounds were detected in the pre-dredge Duwamish core samples, all at levels much lower than found in the contaminated sediments at Denny Way (see Table 2-2). Four HPAHs (fluoranthene, pyrene, benzo(a)anthracene, chrysene) and phenol were found in all four cores. The LPAH phenanthrene was found in three cores. The HPAHs benzo(b)fluoranthene, benzo(k)fluoranthene and benzo(a)pyrene were detected in the two cores with the highest concentrations. Acenaphthene, fluorene, anthracene, dimethyl phthalate, benzoic acid, and 4-methylphenol were detected in one core. This particular sample had the highest concentrations of all compounds detected in the pre-dredge analysis, roughly three times higher than the next highest concentrations.

No pesticides or PCBs were detected in any pre-dredge core samples. Two volatile compounds, acetone and 2-butanone (MEK), were found in one sample and are expected to be sampling artifacts. Acetone and MEK are commonly detected in sampler blanks and are found in most of the volatile organic samples that Metro's Environmental Laboratory processes. The acetone and MEK contamination might be from glassware and apparatus at the laboratory. All metals were well below PSDDA screening levels. The Duwamish River sands met the PSDDA criteria for organics and metals.



Process for compositing the four cores collected from the area of capping material:

Composite		Core Sections Composited	
1	=	A1 + B1	(0'–4')
2	=	A2 + B2	(4'–12')
3	=	C1 + D1	(0'–4')
4	=	C2 + D2	(4'–12')

Figure 2-1. Schematic of Duwamish River Sediment Core Divisions

TABLE 2-2. Duwamish River Sediment Samples

Composite Locator	1 LTXP06				2 LTXP06				3 LTXP07				4 LTXP07			
Date Sampled	Apr 20, 89				Apr 20, 89				Apr 20, 89				Apr 20, 89			
Sample Number	8905264				8905265				8905266				8905267			
% Solids:	87				74				87				70			
BNA Organics (µg/kg dry)	**Value**	**Qual**	**MDL**	**RDL**	**Value**	**Qual**	**MDL**	**RDL**	**Value**	**Qual**	**MDL**	**RDL**	**Value**	**Qual**	**MDL**	**RDL**
LPAHs																
Acenaphthene		<MDL	2	4		<MDL	3	5		<MDL	2	4	5.1		3	5
Fluorene		<MDL	2	5		<MDL	3	6		<MDL	2	5	6		3	6
Phenanthrene		<MDL	2	5	15		3	6	8.6		2	5	56		3	6
Anthracene		<MDL	2	5		<MDL	3	6		<MDL	2	5	11		3	6
HPAHs																
Fluoranthene	5.7		2	6	26		4	7	11		3	6	69		4	7
Pyrene	5.3		2	5	30		3	6	14		2	5	89		3	6
Benzo(a)anthracene		<MDL	2	5	9.6		3	6		<MDL	2	5	29		3	6
Chrysene		<MDL	2	5	15		3	6	5.3		2	5	46		3	6
Benzo(b)fluoranthene		<MDL	7	14		<MDL	9	18		<MDL	8	15	39		10	19
Benzo(k)fluoranthene		<MDL	7	14		<MDL	9	18		<MDL	8	15	43		10	19
Benzo(a)pyrene		<MDL	5	9		<MDL	5	11		<MDL	5	10	34		6	12
Other BNA																
Benzoic Acid		<MDL	10	29		<MDL	10	34		<MDL	10	29	60		10	36
4-Methylphenol		<MDL	5	9		<MDL	5	11		<MDL	5	10	37		6	12
Volatiles (µg/kg dry weight)																
2-Butanone (MEK)		<MDL	6	11		<MDL	7	14		<MDL	6	11	39		7	14
Acetone		<MDL	6	11		<MDL	7	14		<MDL	6	11	91		7	14
Metals (mg/kg dry weight)																
Mercury		<MDL,E	0.2		0.04	E			0.02	E			0.04	E		
Antimony	0.49	E			0.32	E			0.51	E			0.61	E		
Thallium																
Arsenic	8	E			7	E			6.2	E			8.3	E		
Selenium																
Aluminum																
Barium																
Beryllium																
Cadmium	0.07	E			0.14	E			0.06	E			0.24	E		
Chromium																
Copper	13	E			13	E			14	E			30	E		
Iron	39000	E			35000	E			34000	E			39000	E		
Lead	5.9	E			9.5	E			7.9	E			20	E		
Manganese																
Nickel	29	E			28	E			28	E			33	E		
Silver	0.36	E			0.38	E			0.34	E			0.3	E		
Zinc	80	E			89	E			83	E			110	E		

<RDL - Detected below quantification limits
<MDL - Undetected at the method detection limit
B - Blank contamination
G - Low standard reference material recovery
L - High standard reference material recovery
E - Estimate based on high relative percent difference in duplicate, high relative standard deviation in triplicate, or high or low surrogate recoveries

SECTION 3

CAP PLACEMENT

Once a demonstration capping project was agreed upon by the cooperating agencies, sand was barged to the Denny Way site from the Corps' dredge site in the Duwamish River. This section documents the first two objectives in the monitoring plan for the Denny Way sediment cap. The first objective was to ensure that water quality standards for dissolved oxygen were maintained during cap placement. The second objective was to document the sediment cap placement, thickness, and settlement. The sediment-profile camera survey, as it relates to the placement of the cap, also is discussed in this section

WATER COLUMN DISSOLVED OXYGEN LEVEL

The increase in turbidity of the local water column during cap placement was a concern to the permitting agencies. Therefore, the agencies required that water column monitoring be included in the monitoring plan as a permit condition. Capping was to stop if the dissolved oxygen levels dropped below minimum standards or if there were any fish observed to be in distress within the capping area. However, if monitoring during the initial barge dumps showed no problem with oxygen levels, then monitoring could be discontinued.

Water column samples were collected at two stations during the spreading of the first and second barge loads of sand. One site, located outside the capping zone, represented natural "background" conditions. The other site was located within the sediment plume created by the release of sand. Samples were taken at the following three water depths: 1 meter below the surface, at mid-depth, and at 1 meter above the bottom (see Table 3-1). Samples were preserved with manganous sulfate and alkali-iodide-azide solution in the field and transferred to Metro's Environmental Laboratory. At the lab, samples were analyzed by standard Winkler titration procedures.

This effort was to ensure that dissolved oxygen levels remained above 5.0 milligrams per liter (mg/L) in the capping zone as required by the Washington State Department of Ecology (Ecology) water quality certification. Dissolved oxygen levels dropped the most at the surface, but the maximum reduction was only 0.7 to 0.9 mg/L. Because the bay water has high dissolved oxygen levels, the small reduction meant

Water Column Dissolved Oxygen Level

TABLE 3-1. Dissolved Oxygen Levels During Capping				
Sampling Date	Depth (meters)	(mg/L) Outside Plume	(mg/L) Inside Plume	Change
3/16/90	1	9.64	8.77	- 0.87
	6	8.79	8.68	- 0.11
	12	8.68	8.64	- 0.04
3/19/90	1	9.81	9.10	- 0.71
	5		8.80	
	10	8.50	7.82	+ 0.03
	20	8.42		- 0.60

that dissolved oxygen concentrations never fell below 7.8 mg/L, thereby remaining well above the Washington State water quality standard both for Elliott Bay, which is in the Class A marine waters category, and for Class AA marine waters. Subsequent capping operations were allowed to proceed without monitoring. At no time throughout the entire capping operation were fish observed to be distressed.

CAP PLACEMENT, THICKNESS, AND SETTLEMENT

Contractors placed the sediment cap at the Denny Way site by using the proven method of slowly releasing sand onto the desired location with a bottom-dump barge. Cost and available equipment were major factors in the decision of how to place the sediment cap. The bottom dump sand spreader system applies a large amount of sand over a large area at one time, cutting time spent in the application process and therefore cost. Another advantage of the system is that it eliminates the need to transfer the sediment from the transporting barge to the marine bottom with a crane or other transfer method.

This method was developed by the Seattle District Corps in 1984 for confined aquatic disposal of contaminated dredged materials in the lower Duwamish Waterway.

Cap Placement

The Corps contractor used a 180-foot-by-50-foot Zeidell split-hull hydraulic barge with a capacity of 1,300 to 1,900 cubic yards of sand per load for placing the Denny Way cap. The hydraulically opened split-hull barge splits lengthwise to discharge its load (see Figure 3-1). The barge was maneuvered during cap placement by two 800-horsepower tugboats. One was positioned perpendicular to and amidships of the barge and the other was positioned at the end of the barge away from shore (see Figure 3-2). The tug positioned amidship provided propulsion by pushing the barge sideways and the tug positioned at the end of the barge, by pushing and pulling, provided steerage. As the barge was pushed sideways, the operator opened the hull from 6 to 8 degrees and slowly spread a 128-foot-wide blanket of sand. The resulting rectangular-shaped barge tracks are shown in Figure 3-3.

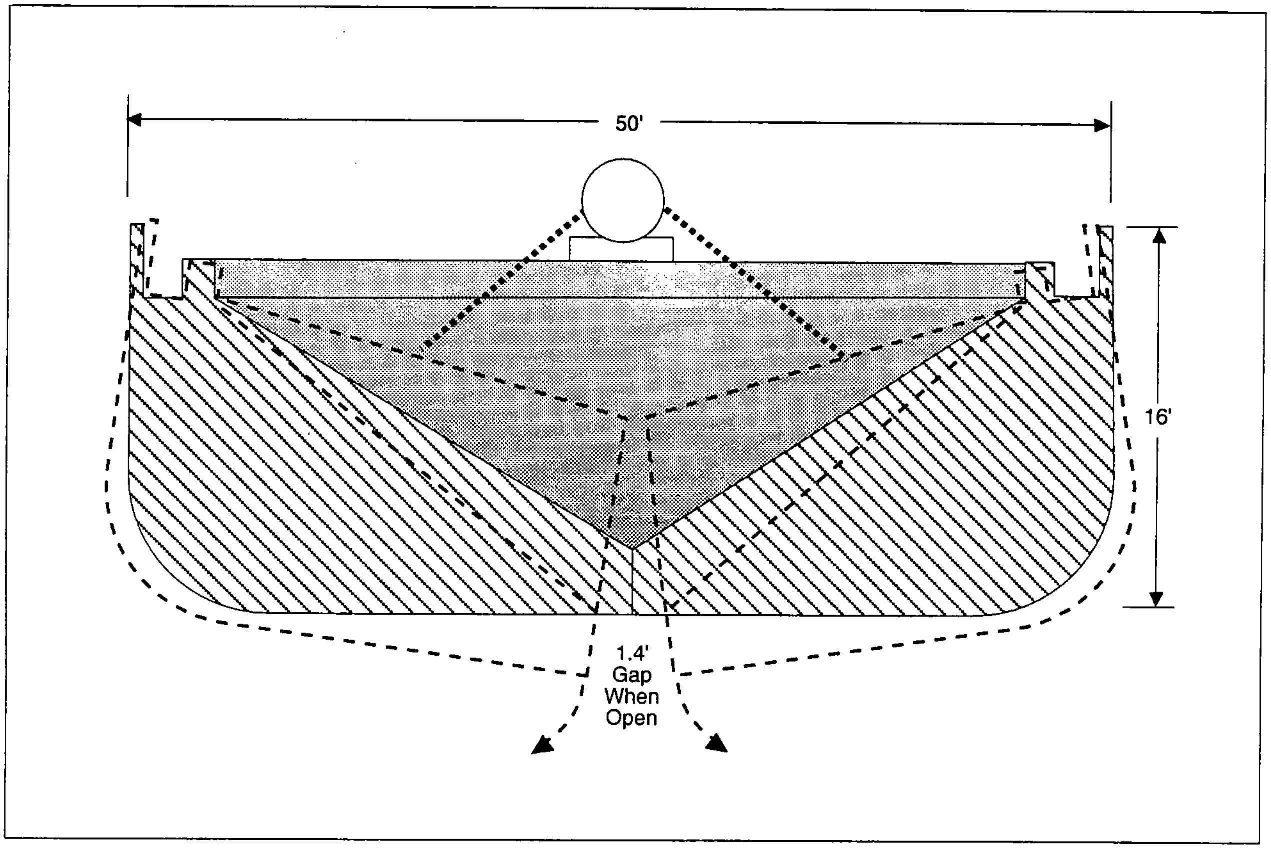


Figure 3-1. Cross Section of Barge

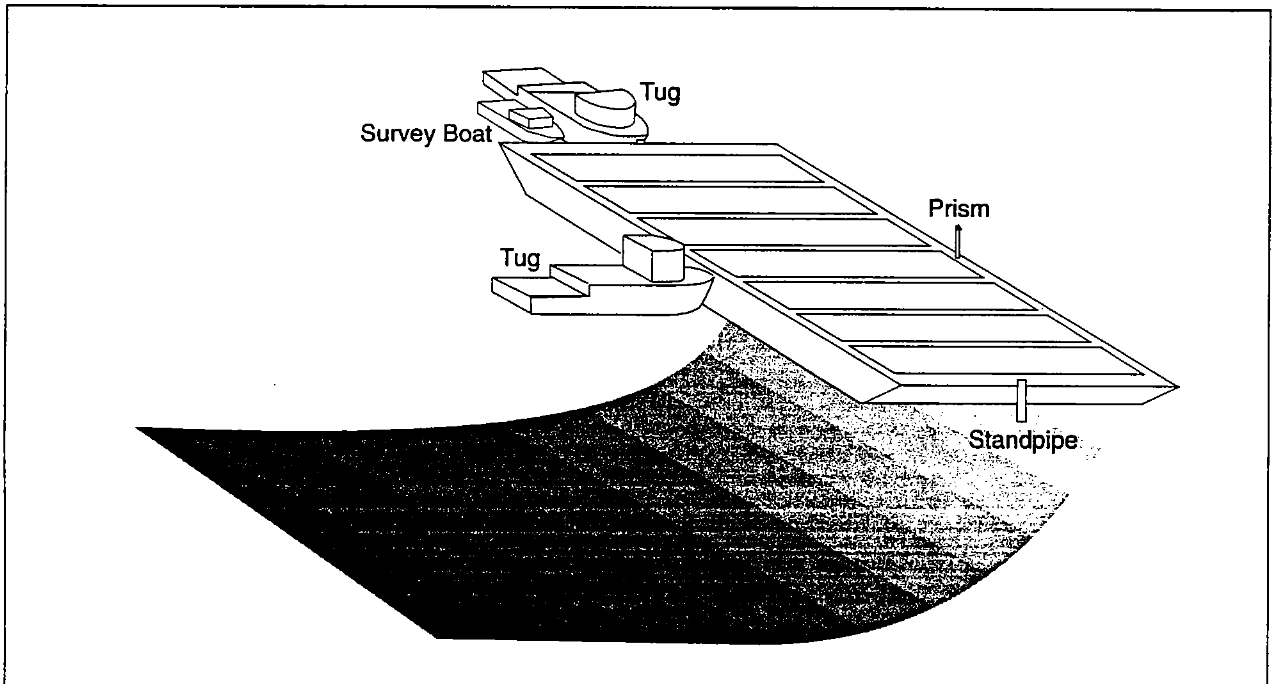
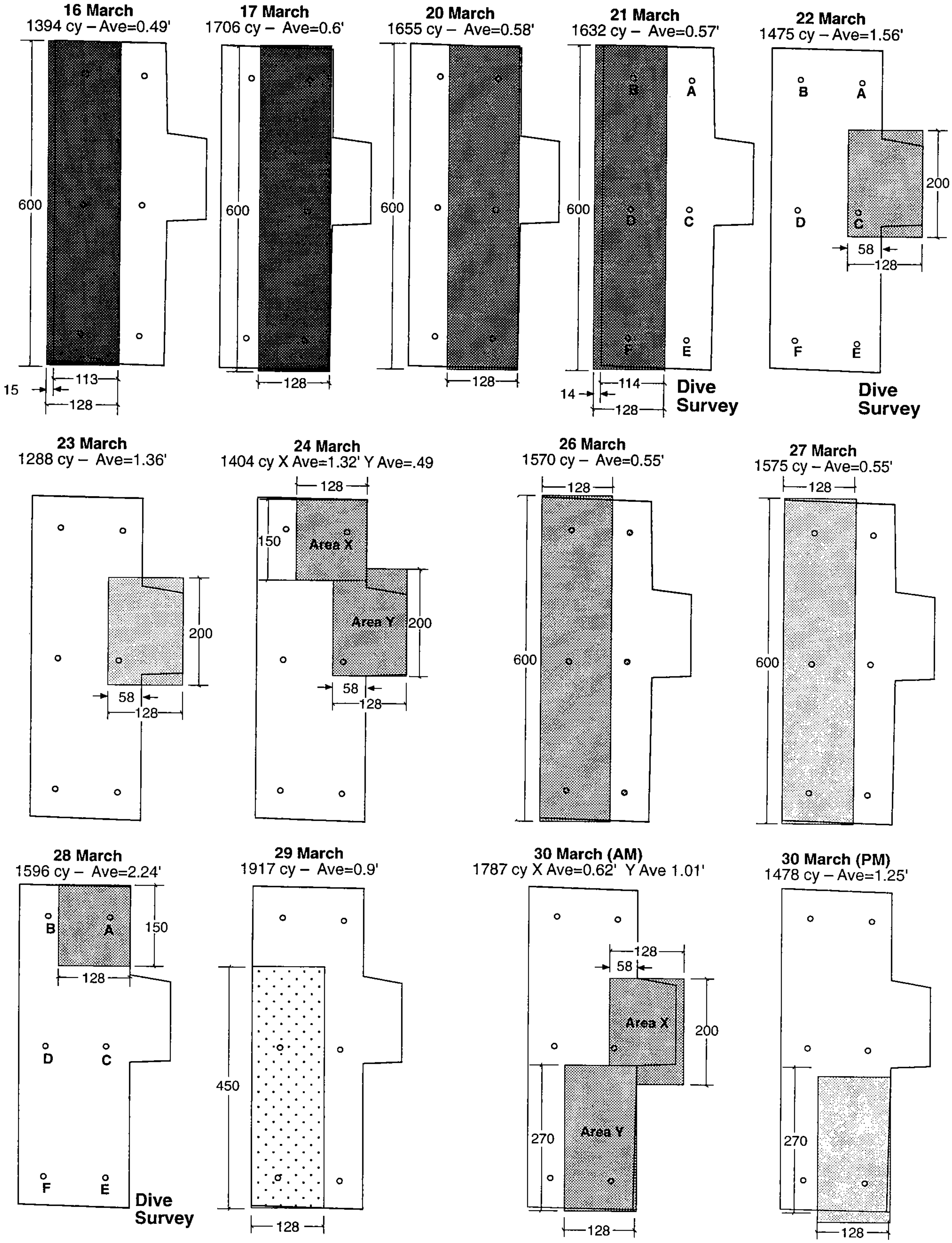


Fig 3-2. Barge Maneuvering

To calculate the theoretical rate of deposition along a barge track, two radio-transmitting tide gauges were used to measure the change in barge draft as sand was being released. The average change in barge draft was then combined with the barge speed to give the rate of sand deposition along a barge track.

Two Hazen radio-transmitting tide gauges were positioned in steel standpipes centered at each end of the barge (Figure 3-4). The tide gauges were sped up to send radio signals every 2 to 2.5 seconds; normally, readings are transmitted every 5 to 20 minutes.

The transducer signals entered into the Corps' land-based hydrographic survey Hewlett-Packard 300 microprocessor via two radio receivers and two RS-232C ports. The hydrographic survey program was modified to read the tide gauge data in lieu of depthsounder data and to provide graphic representations of barge position,



Note: Refer to Figure 3-6.
for spatial concentrations.

Figure 3-3. Barge Tracks

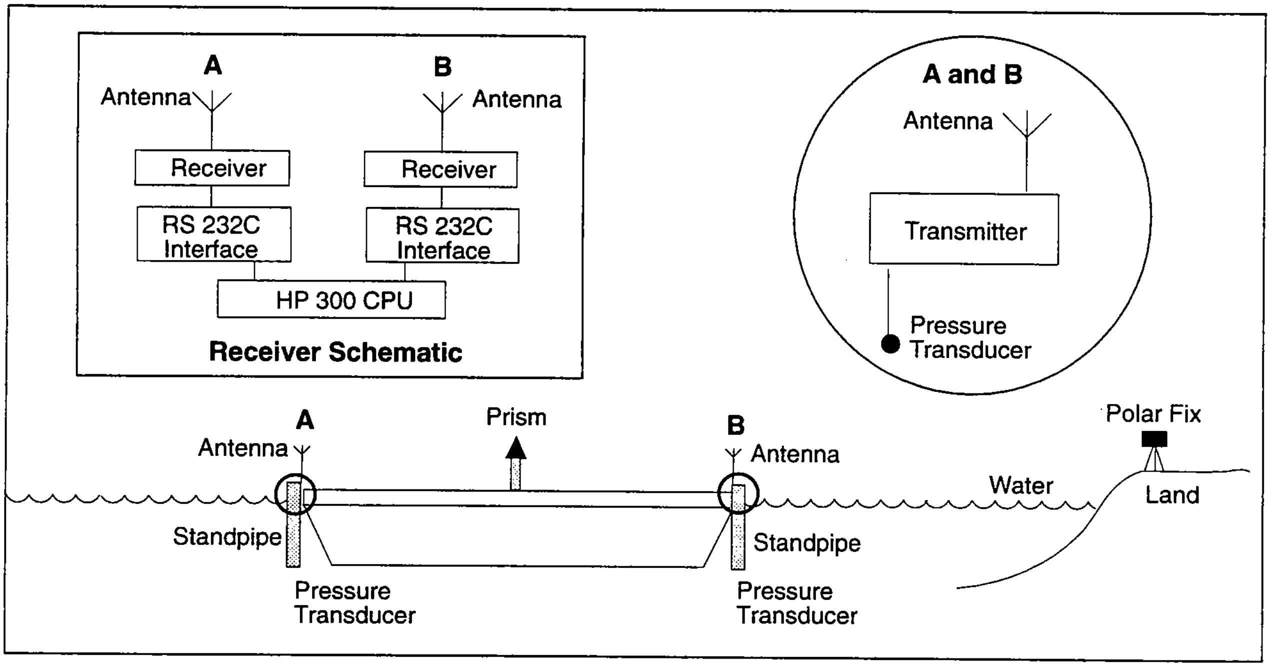


Figure 3-4. Barge Draft and Position Monitoring System

theoretical sand deposition rate, and other information. The software was also developed to replay a capping run graphically and numerically. Programming for this integrated system was developed for the Denny Way capping project with financial support from the Corps' Waterways Experimental Station in Vicksburg, Mississippi. Programming was by Gehagen and Bryant, Tampa, Florida.

A survey crew, using a laser theodolite range/azimuth positioning system following a prism mounted on the side of the barge, supplied position information. Position information appears in Appendix C.

The Corps' survey boat, which tied alongside the tug, was equipped with a computer monitor displaying the same screen information mentioned above, so that adjustments could be made to barge velocity and rate of sand deposition. Each day's average deposition rate and sections capped are displayed in Figure 3-3.

The capped area lies in water depths between 20 and 60 feet (mean lower low datum). It is composed of two adjacent rectangular sections running parallel to shore and measuring 200 by 600 feet and 150 by 70 feet. Thirteen barge loads carrying an approximate total of 20,500 cubic yards were spread over 3 acres with the intent of creating a uniform blanket 3 feet thick.

Cap Thickness

Based on the types of benthic infauna living in Elliott Bay bottom sediments, a 3-foot cap of sediment should effectively prevent animals from digging through the layer and into the contaminants below. The University of Washington Fisheries Research Institute, under contract to the Navy, attempted to document the burrowing depth limits for the burrowing shrimp *Axiopsis spinulicauda* using Kasten cores collected to a sediment depth of approximately 6 to 10 feet in Port Gardner. While the study was not exhaustive, and should only be considered a preliminary evaluation, it documented burrowing depths of less than 0.5 meters for this species. The study showed no evidence of biogenic activity, including burrow structures of any kind (for example, from *Molpadia*), deeper than 0.72 meters (David Kendall, the Corps, personal communication, October 13, 1993).

Bathymetric surveys and barge track records were used to estimate cap thicknesses, while direct measurements were made using sediment core samples and measuring stakes.

Bathymetric surveys. Bathymetric surveys were conducted before, during, and after the capping process to document cap placement and thickness. Differences in water depth measurements were to be translated into cap thicknesses. However, the surveys did not accurately quantify the cap thickness because of the complexity of the slopes, settling of the sediments during capping, and the wide range in depths. Another problem was that the location of the laser positioning system was different for the pre-cap survey than for subsequent surveys. The unit was placed on the end of Pier 90 for the pre-cap survey, and for subsequent surveys it was placed on the Denny Way outfall structure. Therefore, the information obtained from the survey could not be used.

Core Samples. Another method used to determine cap thickness was to measure the core samples taken from the cap for chemical analysis. The core samples were driven through the capping sand and into the native mud. The interface between the contaminated mud and the sand cap was easily observed in core samples. Therefore, an estimation of cap thickness was taken by measuring the distance from the mud interface to the top of the core. Table 3-2 shows the length of the core samples during the three years of sampling.

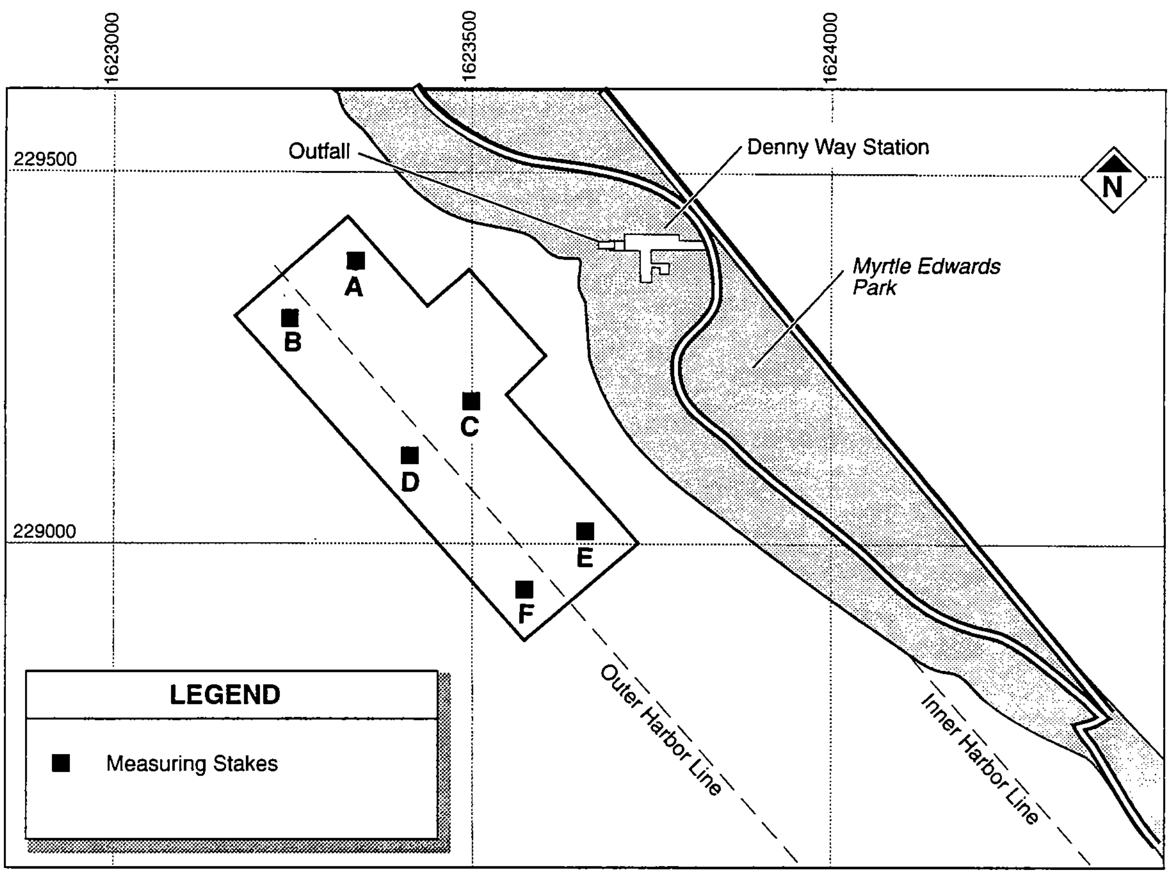
TABLE 3-2. Core Length (in feet)

Core Site	1990 Cap Thickness	1991 Cap Thickness	1992 Cap Thickness
N	2.58	2.63	2.08
N Replicate			2.25
O	2.25	1.92	1.83
P	2.58	2.04	2.21

There were two possible sources of error when estimating the cap thickness from core lengths. First, when the coring tubes are hammered into the sediments, the sediments inside the core tube may compress. The length of the core will often be shorter than the actual cap thickness. Second, as the sediments in the core tube compact, they may begin to push away some sediments instead of sliding farther up into the core tube. The resulting core length would be less than the cap thickness because of the absence of some cap material in the sample. While there is error involved in measuring the cap thickness from core samples, this method does give some indication of cap thickness.

Barge Track Records. Cap thicknesses were predicted using the amount of sand deposited during a release on a barge track divided by the area of the barge track. This predicted thickness is a simple calculation and assumes that all sediments dumped from the barge land on site. While this is not accurate enough to determine actual cap thickness, it is used to estimate how much sand each barge track will need, and as a comparison to determine how accurately the sediments were placed.

Measuring Stakes. Before capping, bottom stakes and settling plate assemblies were set at six locations to directly measure cap thickness and settlement (see Map 3-1). The stakes were 13- to 18-foot-long, 1-inch-diameter pipes, pounded in by a scuba diver, with 4.70 to 4.81 feet left exposed (see Figure 3-5). Settling assemblies are a 3-foot-square, half-inch-thick plywood plate sitting horizontally on the pre-cap seafloor, attached to a vertical 4-inch-diameter PVC-plastic cylinder long enough to remain exposed after capping. The settling plate assembly was mounted over the exposed section of each stake and could slide down the stake as the contaminated sediments were compressed under the weight of the overlying



Map 3-1. Measuring Stake Locations

cap. A metal clamp fastened to the stake marked the position where the PVC cylinder extended before capping. Settling measurements were taken from the bolt that fastens the clamp.

Assuming that the deeply buried stake remains stationary, the distance between the bolt and top of the cylinder is a direct measurement of settling. Cap thickness was calculated as the difference between the exposed length of pre-cap stake and the post-cap distance from the top of the stake to the new sediment surface. Using a surveyor's rod, scuba divers measured both stake height and settlement at each of the six stations soon after capping and again annually.

Cap Placement, Thickness, and Settlement

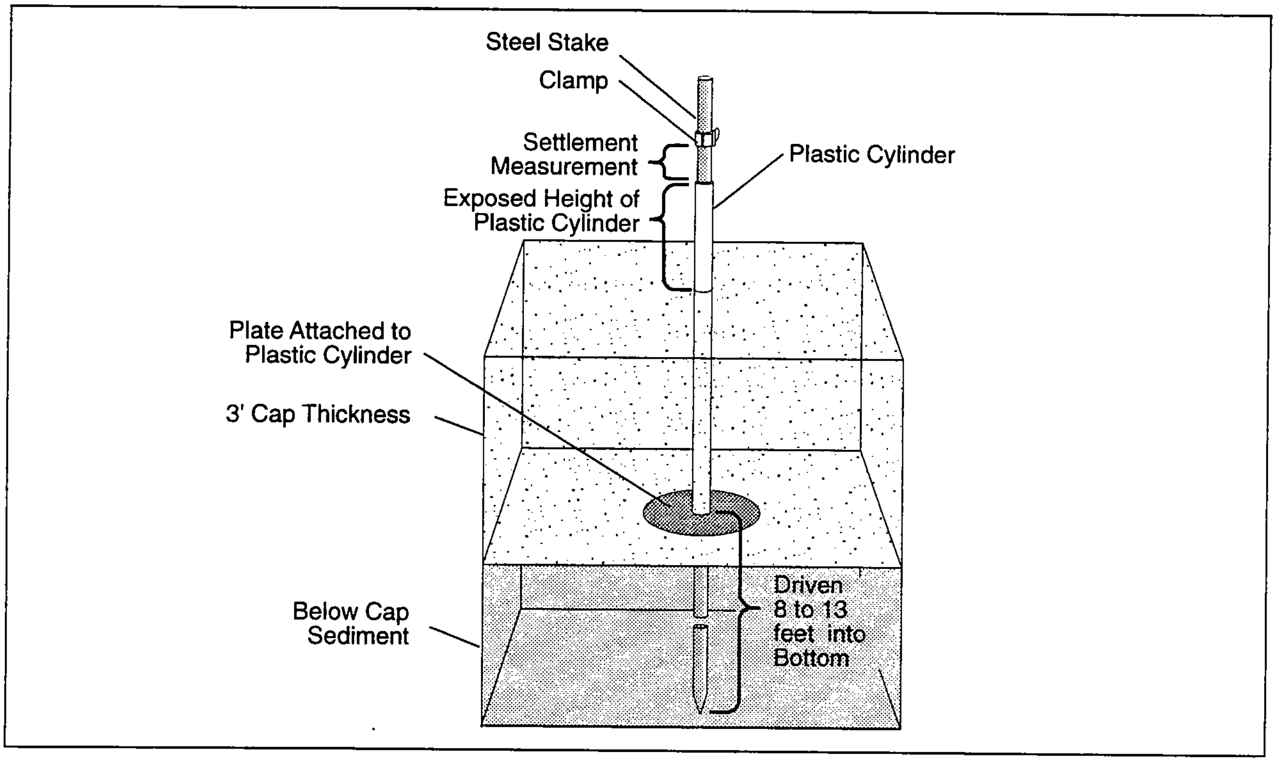


Figure 3-5. Measuring Stake Schematic

Stake A was bent at the beginning of capping when the barge was opened too quickly at the end of a barge run and the last amount of sand along the side of the barge slid out as a cohesive block. The diver estimated that the stake was bent at a 45-degree angle; therefore, cap thickness is a calculated approximation. Originally 4.73 feet were exposed, leading to a height estimate of 3.34 feet after the stake was bent. Settlement data for Stake A are not reliable and will not be considered in our evaluation.

Discussion. Table 3-3 summarizes stake measurements and predictions from barge track records. The project objective was to create a cap 3 feet thick, but the average cap thickness shortly after capping was 2.56 feet. At all stakes there were at least 2 feet of sand, except Stake E, where 1.69 feet were recorded. Average cap

TABLE 3-3. Cap Thickness, Settlement, and Stake Height (in feet)

4-Apr-90 Stake	Pre-cap Height (H0)	Predicted Thickness	Post-cap Height (H1)	Plate Settlement (S1)	Cap Thickness (H0-H1=T1)		
A*	4.10	4.7	0.40	0.175	3.70		
B	4.73	2.2	1.73	0.375	3.01		
C	4.70	5.2	1.85	0.300	2.85		
D	4.81	3.1	2.55	0.175	2.26		
E	4.79	3.4	3.10	0.950	1.69		
F	4.79	3.1	2.15	0.550	2.64		
28-May-91 Stake	**Pre-cap Height (H0)**	**Predicted Thickness**	**Post-cap Stake Height (H2)**	**Plate Settlement (S2)**	**Cap Thickness (H0-H2=T2)**	**Cap Thickness Change (T2-T1)**	**Plate Settlement Change (S2-S1)**
A*	4.10	4.7	0.50	0.125	3.60	-0.10	-0.050
B	4.73	2.2	1.68	0.725	3.06	0.05	0.350
C	4.70	5.2	1.65	0.365	3.05	0.20	0.065
D	4.81	3.1	2.70	0.125	2.11	-0.15	-0.050
E	4.79	3.4	3.17	1.200	1.63	-0.06	0.250
F	4.79	3.1	2.00	0.985	2.79	0.15	0.435
18-May-92 Stake	**Pre-cap Height (H0)**	**Predicted Thickness**	**Post-cap Stake Height (H3)**	**Plate Settlement (S3)**	**Cap Thickness (H0-H3=T3)**	**Cap Thickness Change (T3-T2)**	**Plate Settlement Change (S3-S2)**
A*	4.10	4.7	0.50	0.275	3.60	0.00	0.150
B	4.73	2.2	1.70	0.900	3.03	-0.03	0.175
C	4.70	5.2	1.70	0.600	3.00	-0.05	0.235
D	4.81	3.1	2.65	0.250	2.16	0.05	0.125
E	4.79	3.4	3.10	1.175	1.69	0.06	-0.025
F	4.79	3.1	2.00	1.150	2.79	0.00	0.165

* Stake A was bent. Height was estimated.

thickness changed a small amount from year to year, mostly in the range of 0.05 to 0.1 foot, with the largest change being 0.2 foot at Stake C in 1991. The changes were small, however, and showed no trend. The differences were greater between 1990 and 1991 than between 1991 and 1992; this may be because the cap surface smoothed out and became flatter during the second year. Since the changes in cap thickness were small and showed no trend, the recorded differences can be attributed to measurement error. Overall, average cap thickness changed very little during subsequent years, indicating that the cap has not eroded.

The thickness of the cap was predicted using the sum of the daily average deposition rates for each section from barge track records. This calculation showed that 5,000 cubic yards or 25 percent more capping material was used than the volume calculated as necessary for covering the capping area to a 3-foot depth. There were at least three reasons for the difference between predicted and actual thickness (see Figure 3-6).

First, sand distribution appears to be influenced by currents near the surface and throughout the water column. The difference between predicted and actual

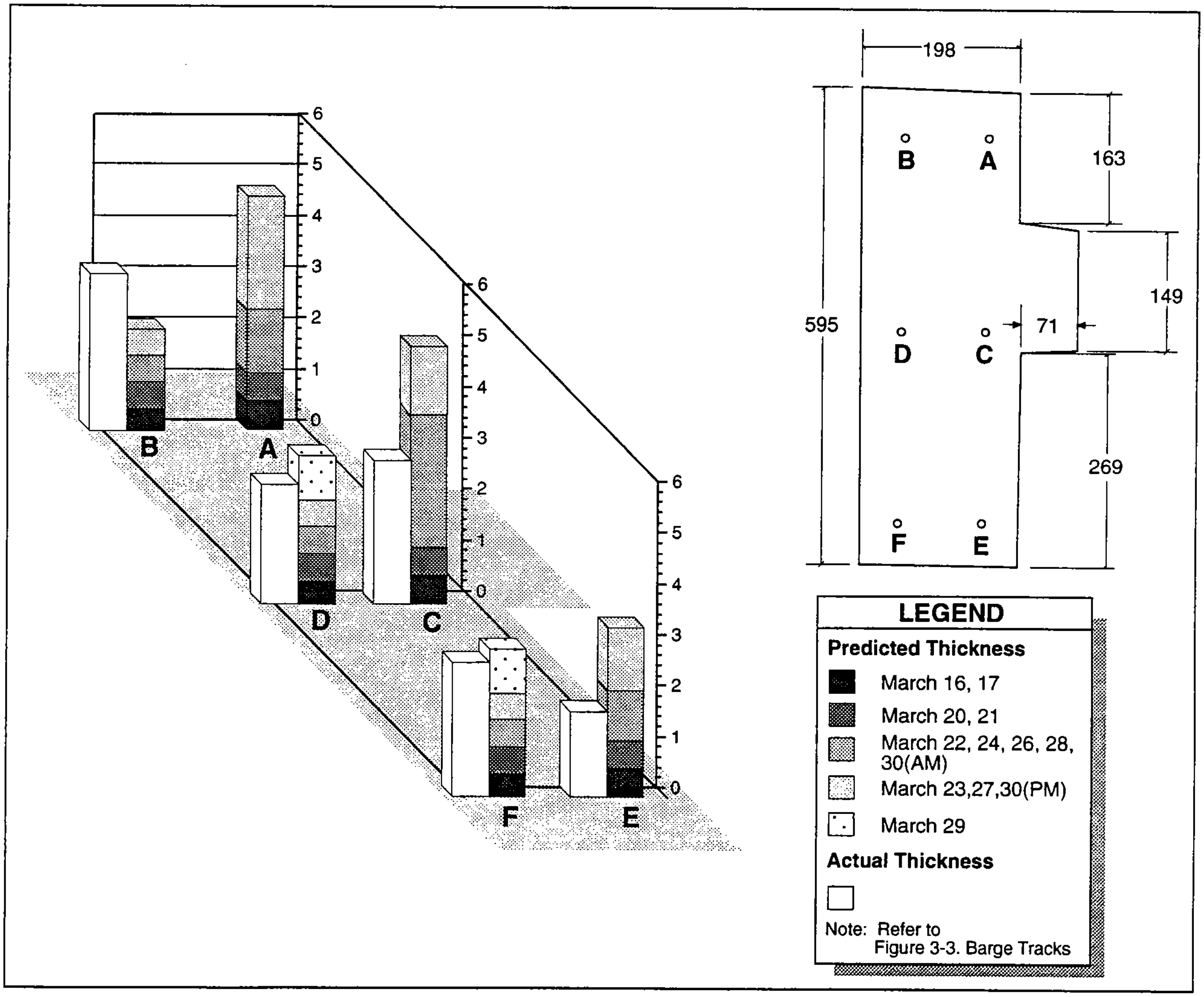


Figure 3-6. Predicted and Actual Thicknesses

thickness for nearshore stakes (A, C, and E) was greater than for seaward stakes (B, D, and F). Nearshore differences ranged from 1.7 to 2.3 feet, while stakes D and F lost only 0.8 and 0.5 feet respectively. Stake B was capped with more sand than predicted. Cursory analysis of these results suggest that a roughly west-northwesterly current was present during capping. This is a realistic expectation given the season, shoreline, and geographic orientation of the cap site.

Second, estimations of predicted thickness assumed a steady release of sand throughout the section of concern. In reality, some large spontaneous releases of sand resulted when barge halves were opened too quickly or the sand cohered as blocks, like the release that bent Stake A.

And finally, the predictions assumed that the barge did not exceed the target cap outline while releasing sand. Although every effort was made to stay on track, the very nature of barge operations made it difficult to stay exactly within the planned track outline. An additional difficulty was that the barge runs, as designed, were approximately 600 feet long. These long runs made it difficult to control the slow release of sand. In the subsequent capping project at Pier 53–55, the Corps shortened the barge runs by half, which resulted in greater control and less sand loss.

In summary, calculating thickness based on the volume of sand placed and the barge track records was not an accurate means to determine actual cap thickness. The actual process was more variable than the estimate assumed, because of currents and the dynamics of tugboat operation.

Cap Settlement

A significant amount of settlement occurred, particularly at the two southernmost sites (Table 3-3). Within one week after capping, Stake E showed 0.95 foot of settlement and F showed 0.55 foot. Both stakes showed a smaller amount of settlement after the first year and appeared to be approaching stability after the second year. The usable northern site, Stake B, settled almost as much during the first year as it did during capping and continued to settle at a considerable rate the second year. The two centermost sites, Stakes C and D, behaved erratically. They seemed to be the most stable, settling little during capping and remaining quite stable the first year. However, both had marked increases the second year.

Settlement data are summarized in Table 3-3. The values in Table 3-3 are cumulative as measured from the clamp bolt, not rates of settlement per year. The settlement measurements at Stake D in 1991 and Stake E in 1992 imply that minor rebound may have occurred. The amount of rebound in both instances, however, is so minor that it can be contributed to measurement error. Therefore, at present there is no apparent danger to the cap's integrity from rebounding sediments.

Speculation about the reasons for settlement and the variability shown was inconclusive. Historical and current total solids data do not demonstrate "softer" sediments in the south end. According to the 1990 core analysis, the native sediments in the south have a slightly higher ratio of muds to sands than the north. This may explain why E and F settled more than B. However, while stakes nearest the shore have more sand and therefore should be more stable than the farther offshore stakes, the opposite relationship was found: offshore stakes (D and F) were more stable than comparable nearshore stakes (C and E, respectively).

SEDIMENT-PROFILE CAMERA SURVEY

Metro contracted with Science Applications International Corporation (SAIC) to conduct a sediment-profile camera survey of the Denny Way sediment cap. The survey was completed on October 23, 1991, with a Metro support crew and the research vessel *RV Liberty*.

The purpose of the camera study was to document the nature of the benthic communities on the cap and determine the boundaries of the capping material. This section summarizes the SAIC report. The entire study report appears in Appendix D.

Camera System

The photographic system used in the sediment-profile camera survey is a REMOTS (see Figure 3-6). The actual camera is a Benthos Model 3731 sediment-profile camera. The camera has an internal strobe light and is mounted above a wedge-shaped optical prism with a Plexiglas faceplate. The back of the prism has a mirror mounted at a 45-degree angle to reflect the profile of the sediment-water interface. The camera and prism are mounted on a frame that can be lowered from a boat to the sea bottom with a winch.

Once the camera is on the bottom, an adjustable, "passive" hydraulic piston slowly forces the wedge-shaped prism into the bottom sediment. The slow rate of

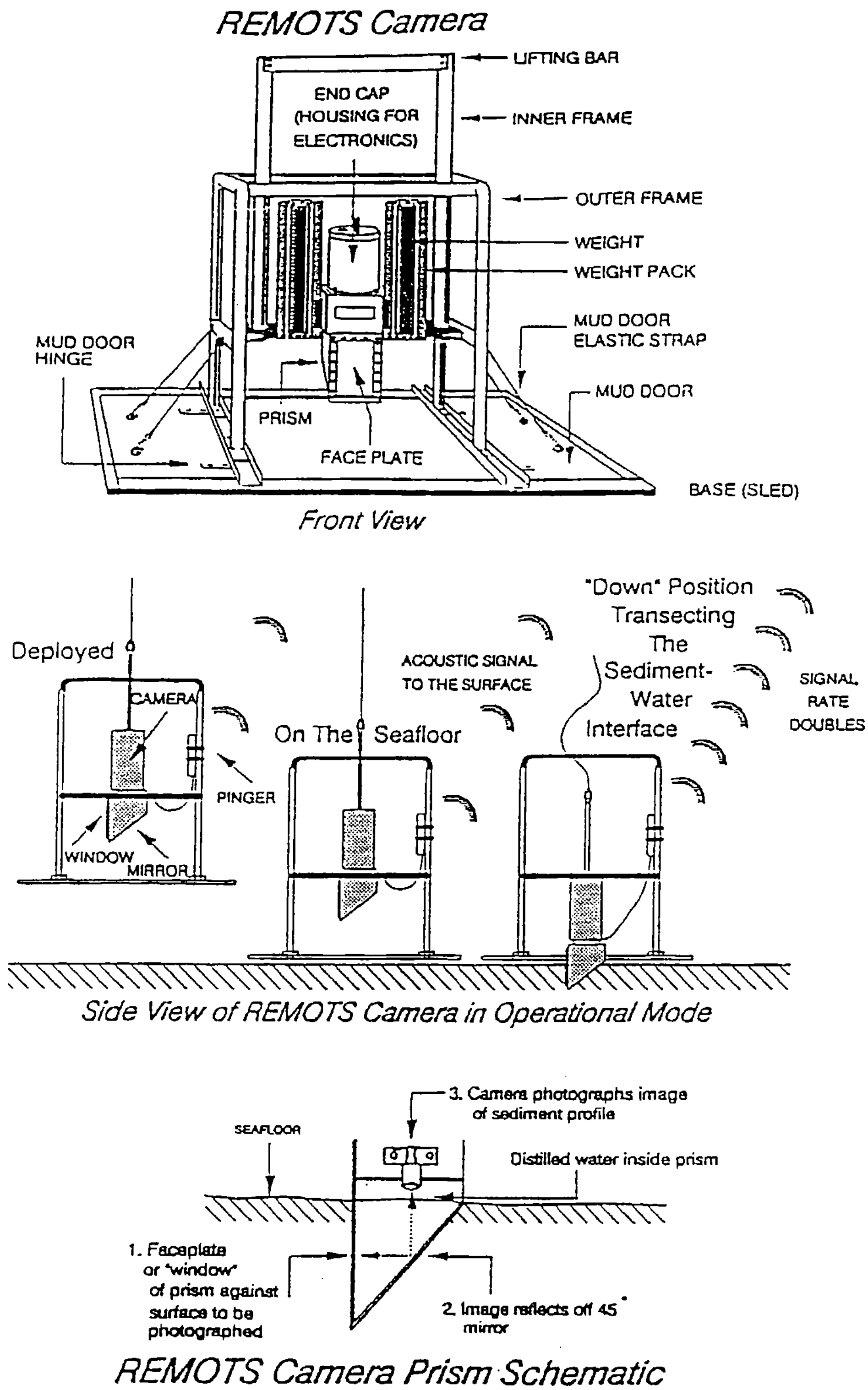


Figure 3-7. Sediment-Profile Camera

penetration minimizes sediment disturbance. The prism is driven several centimeters into the sea floor by the weight of the assembly. A camera trigger is tripped on impact with the bottom, activating a 13-second time delay on the shutter release. This gives the prism time to penetrate to its maximum depth before a photo is taken.

Photographic Stations

To provide adequate spatial coverage in the delineation of cap material, the camera survey team used a sampling design composed of three cross-slope and two along-slope transects.

The survey team used a laser theodolite range-azimuth positioning system similar to the one used for cap placement. A shore-based survey crew aimed a laser at a prism on the *Liberty* and, by monitoring the range and azimuth, directed the vessel over the ship's radio to the sampling station. Once at the station, the crew lowered the camera to the sea floor and took a picture. When the camera was on the bottom, the crew also recorded the location of the station as an angle and distance.

During the camera survey, a total of 106 sediment-profile images were collected from 38 stations within and adjacent to the cap boundary. Three replicate images were obtained from 26 of the 38 stations, while four replicate images were collected from two stations, and two replicate images were collected at each of the remaining stations.

Results

To determine the boundaries of the Denny Way cap, the dredged sands placed on the site had to be distinguished from the native sediments. The camera images showed that the cap was characterized by poorly sorted medium- to fine-grained sands interspersed with a fine-grained material. This mixture gave the capping sediments a mix of high and low light reflectance. Rounded reddish granules, interpreted to be pieces of broken and weathered brick, also are interspersed in the sands. Other characteristics of the capping sands are leaf and twig debris coating the sediment surface and cohesive clasts of fine-grained clay that were noted in the core and surface samples.

The sediment cap is composed of mostly 3 to 2 phi (0.12 to 0.25 mm) fine sands. At stations where 3 to 2 phi sands were present, most of the sands were closer to the larger 2 phi size than 3 phi. In the shallower areas, images showed coarser-grained 2 to 1 phi (0.25 to 0.5 mm) medium sands.

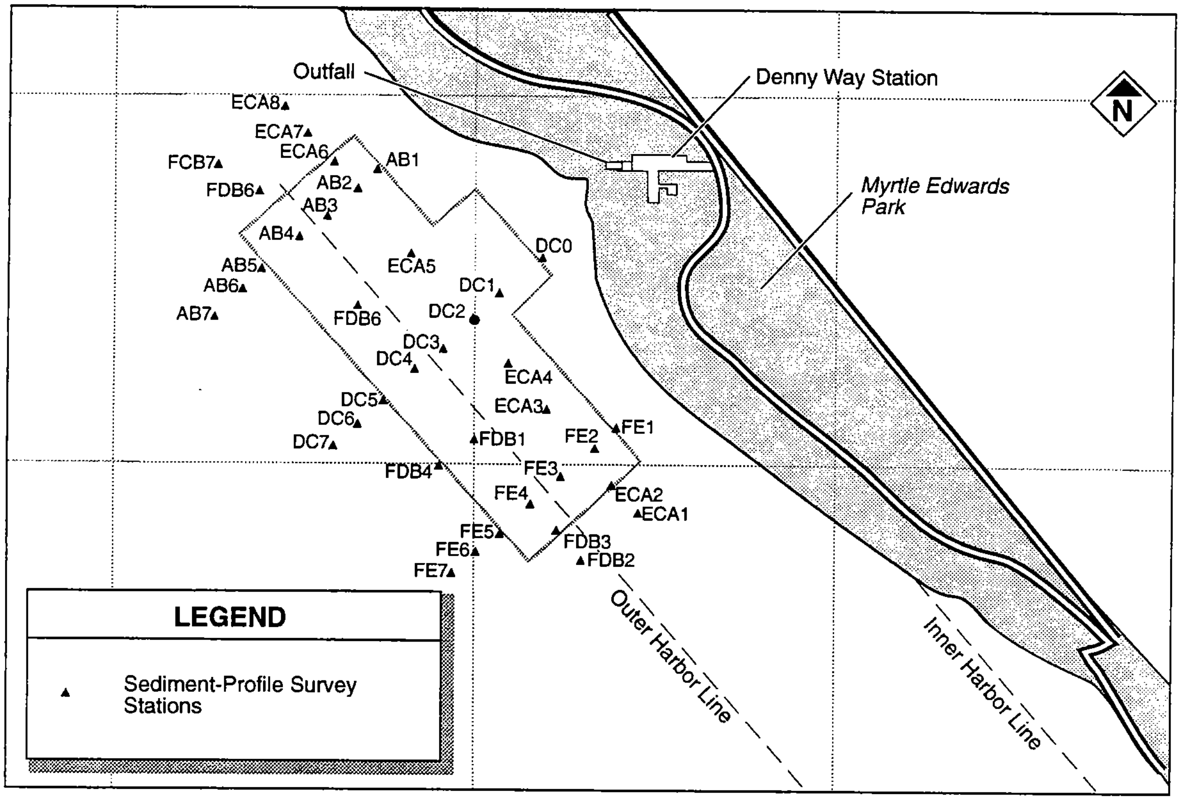
Cap surface relief or "boundary roughness" ranged from 0.04 to 1.78 cm, with 70 percent of the boundary roughness values ranging from 0.5 to 1.5 cm. These are modest values. When boundary roughness features are caused by the feeding activity of benthic animals and their predators, the boundary roughness values may be on the order of several centimeters. The boundary roughness features observed from the images within and adjacent to the sediment cap are a combination of mounds caused by clay lumps, debris, or other physical features, and mounds caused by marine animals living in or near the bottom.

Discussion

The sediment-profile survey indicates that the capping sands are present beyond the projected boundaries of the cap. The capping sands extend the farthest in the offshore or southwestward direction. Evidence supporting this observation includes the presence of the reddish granules, interpreted to be pieces of brick associated with the cap material, among high reflectance sands overlying the fine-grained, homogenous gray substrate that is interpreted to be native sediment. Camera images also showed old inactive structures made by benthic organisms in the underlying silts and clays that have been covered by capping sand.

When dredged material is dispersed by barge, the descending mass typically behaves like a density current. When this current hits the sea floor, it spreads radially. As it spreads, it constantly loses kinetic energy, and the densest (coarsest) sands settle first. The dredged material would travel farther downslope, as the density current would more readily flow along a potential gradient. At Stations AB7, DC7, and FE7 (see Map 3-2) offshore of the cap boundary, a thin layer of cap material is observed overlying native sediments. At Station AB7, 110 feet offshore of the cap boundary, a layer of cap sand is 6 to 7 cm thick. At Station FE7, 140 feet offshore, the layer is 6 cm thick, and at Station DC7, 210 feet offshore, the layer is 9 cm thick.

At Station AB1 replicate B, located on the northern corner of the cap, the camera prism penetrated through the sand to show the underlying native sediments. The cap was approximately 10 cm thick. These findings tend to support readings from the measuring stakes that suggest that during cap placement water currents may have caused the capping sediments to drift in a west-northwesterly direction. The image from Station AB1/B shows medium to coarse-grained clean sand overlying highly reduced, low light-reflecting muds. A striking feature of the native sediments observed at this station is the presence of methane bubbles within the sediment column. These are identified by the high index of



Map 3-2. Sediment-Profile Camera Survey Stations

refraction at the edges of each gas bubble, which results in a glassy appearance. Methane production within these sediments indicates reducing conditions and high amounts of reactive organic material. Based on the sharp contact between the cap and the underlying native sediments, the cap is effective at physically covering the underlying material. It is unknown if methane gas bubbling through the capping sands is capable of transferring native sediments upward through the cap.

Shoreward of the cap boundary, at Station DC0 in two out of three replicates, the native sediments do not appear to be capped. These sediments are medium to fine-grained sands. A distinguishing characteristic of these native sands is their low reflectance at the sediment-water interface as well as at depth within the sediment column. These sediments apparently have high amounts of sulfides. One of the replicates is located 30 feet inshore of the cap; however, the other two replicates, one of which showed a thin layer of sand, are located within 5 feet of the shoreward edge of the cap. This lack of sand close to the cap could mean the shoreward edge of the cap is thin.

If sediment drift in the west-northwesterly direction caused the inshore edge of the cap to be thin, then capping sands should be present outside of the cap in that direction. While coordinate locations are not available for Station FDB7, the station target area is from 40 to 120 feet outside the cap boundary to the north of the west corner of the cap. At this station, capping sands were present in sufficient thicknesses to prevent the camera prism from penetrating into the native sediments. At Station FDB6, 50 feet to the northwest of the cap, the capping sediments are also thicker than the camera can penetrate.

While the sediment-profile survey transects did not go far enough to determine the farthest extent of the capping sands, the sediment-profile survey stations that are not on the cap support the indications from the cap thickness measuring stakes and the barge track records that large amounts of sand went off the capping site. The sediment-profile survey further indicated that the sand went offsite to the west and southwest. Sands that went offsite to the west probably drifted with a west-northwesterly water current, and the sands that went offsite to the southwest probably followed the downslope gradient in the offshore direction.